DOCUMENTA GEIGY

SCIENTIFIC TABLES · SEVENTH EDITION

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II J. G. Baer, E. Berger, H. Brodhage, L. P. Garrod, R. Geigy, O. Gsell and H. P. R. Seeliger, 'Pathogenic Organisms and Infectious Diseases' (in preparation)

DOCUMENTA
GEIGY

SCIENTIFIC TABLES

SEVENTH EDITION

EDITED BY K DIEM AND C. LENTNER
PUBLISHED BY J.R GEIGY S A , BASLE, SWITZERLAND

Publisher's Foreword

This 7th edition of the *Geigy Scientific Tables* pursues the aim of earlier editions, namely to provide doctors and biologists with basic data in a concise form and thus spare them much searching in the literature.

In the 6th edition the main changes from the previous edition consisted of an extension of the mathematical, physical and chemical data and a new chapter devoted to biochemistry; in this edition the principal difference is the greatly expanded medical part of the book. The increasing extent to which physical, physicochemical and biochemical methods are finding application in medicine has resulted in the last few years in an immense accumulation of new data whose proper evaluation can be undertaken only by specialists. For this reason we have been compelled in this edition to enlist the cooperation of outside experts to a much greater degree than in the past. Here we would like to thank all those who have contributed in this way – whether in the form of original article or expert advice – for their invaluable help. Their names are listed overleaf.

We would also like to express our appreciation once again of the assistance of all those who have made suggestions or drawn our attention to errors. If we have been unable to adopt all the suggestions put to us, this has been due to the limits set us by the physical compass of the *Scientific Tables*. Users can rest assured that we shall continue to do our best to meet their wishes in the future.

J. R. GEIGY S.A., Basle

Editors' Foreword

All the fields covered by the 6th edition of the *Scientific Tables* are again represented in this new edition with the exception of 'Infectious Diseases', the chapter on which appears separately as a supplement. The thoroughgoing revision of the remaining chapters has resulted in a number of major changes, of which the following are worthy of special mention

The data on units of measurement and the physical constants take account of decisions and recommendations adopted by the various international commissions up to March 1969, in particular those concerned with the introduction of the International System of Units The adoption of the unified scale of atomic weights based on the isotope carbon-12 has involved the recalculation of molecular weights throughout the book In the physicochemical part of the book a chapter on pH standards has been added, and the data on buffer solutions have been recalculated to the pH scale of the National Bureau of Standards.

'Biochemistry' has been greatly enlarged, particularly by the inclusion of more data on nucleic acids and protein and fatty-acid synthesis as well as by the addition of a new chapter on 'Inborn Errors of Metabolism' Throughout this section – as in the other sections – the recommendations on nomenclature made by the International Union of Pure and Applied Chemistry and the International Union of Biochemistry have been largely adhered to

In the section on nutrition due regard has been paid to the considerable advances made in recent years in knowledge of the nutritional significance of the vitamins; and important new sources have been utilized in revising the data on the composition of foods

Of the chapters comprising the section on 'Composition and Functions of the Body', those on the composition of the body, renal function and respiration in particular have been greatly extended Under the heading of body fluids the subject of blood enzymes has been given much more thorough treatment, and chapters on the synovial fluid and sweat have been added

Under body measurements the normal data of pregnancy have been completely revised, and the chapter now includes tables of weights of the organs

The final section of the book is now that on hormones, an arrangement that has permitted the inclusion of more recent endocrinological data from this rapidly advancing field than would otherwise have been possible

K. DIEM
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Contents

Contents

Notes for the guidance of users

Apart from the main contents (above) and general index (pages 765 et seq.) the user will find the contents of the chapter on 'Statistical Methods' on page 145, that of the chapters on 'Constituents of Living Matter' and 'Metabolism' on page 307; in addition there is a separate detailed index to the chapter on 'Statistical Methods' on pages 197–198.

Zero values are indicated by the figure 0 throughout the book. A dash (–) signifies that the value is unknown, and this sign should on no account be interpreted as a zero value.

As a rule, the meanings of symbols and abbreviations are given where they first occur. For units of measurement an alphabetical list is available on page 199.

In the numerical tables, a point over the last figure (or figures) indicates a recurring figure (or figures), thus

$$1.\dot{6} = 1.666666\ldots$$
$$1.65\dot{2}7\dot{8} = 1.65278278278\ldots$$

In general the number of places given has been dictated by the space available. The user should abstract as many as he needs and round off accordingly.

Exact values have been distinguished from rounded-off values by printing the last figure in **bold-face** type. Thus, 1.1257 would be the rounded-off value of, say, 1.1257354..., while 1.125**7** is an exact number. This notation is used in particular for the arbitrarily defined values of constants.

When they have been calculated according to statistical procedures (usually as mean value ± 2 standard deviations), normal ranges are given under the heading '95% range' (note that this practice differs from that adopted in previous editions).

For obvious reasons we have had to restrict bibliographical references to a representative selection of recently published original papers and reviews. In fields where research activity is currently high a rather fuller bibliography is given. The abbreviations used in the literature references are those recommended by the UNESCO and WHO (*World Medical Periodicals*, World Medical Association, New York, 1961).

Additional copies of the *Folia medica Geigy* in the inside back cover of this book may be obtained by application to J.R. Geigy S.A., CH-4000 Basle 18, Switzerland.

Mathematical constants

Bernoulli numbers		*Euler numbers*	
n	B_n	n	E_n
1	1/ 6	1	1
2	1/ 30	2	5
3	1/ 42	3	61
4	1/ 30	4	1385
5	5/ 66	5	50521
6	691/2730	6	27 02765
7	7/ 6	7	1993 60981
8	3617/ 510	8	1 93915 12145
9	43867/ 798	9	240 48796 75441
10	1 74611/ 330	10	37037 11882 37525
11	8 54513/ 138	11	69 34887 43931 37901
12	2363 64091/2730	12	15514 53416 35570 86905
13	85 53103/ 6	13	40 87072 50929 31238 92361

Constants

Constant	Value	$\log_{10}$
π	3 14159 26535 89793 23846	0 49714 98726 94133 85435
π^2	9 86960 44010 89358 61883	0 99429 97453 88267 70870
$(2\pi)^{-1/2}$	0 39894 22804 01432 67794	0 60091 00658 20942 47522–1
e	2.71828 18284 59045 23536	$= M$
$M = \log_{10} e = \lg e$	0 43429 44819 03251 82765	
$1/M = \log_e 10 = \ln 10$	2 30258 50929 94045 68402	
γ (EULER's constant)	0 57721 56649 01532 86061	0 76133 81087 83167 61054–1

Prime numbers < 100	
Number	$\log_{10}$ (mantissa)
2	30102 99956 63981 19521
3	47712 12547 19662 43730
5	69897 00043 36018 80479
7	84509 80400 14256 83071
11	04139 26851 58225 04075
13	11394 33523 06836 76921
17	23044 89213 78273 92854
19	27875 36009 52828 96154
23	36172 78360 17592 87887
29	46239 79978 98956 08733
31	49136 16938 34272 67967
37	56820 17240 66994 99681
41	61278 38567 19735 49451
43	63346 84555 79586 52641
47	67209 78579 35717 46441
53	72427 58696 00789 04563
59	77085 20116 42144 19026
61	78532 98350 10767 03389
67	82607 48027 00826 43415
71	85125 83487 19075 28609
73	86332 28601 20455 90107
79	89762 70912 90441 42799
83	91907 80923 76073 90383
89	94939 00066 44912 78472
97	98677 17342 66244 85178

Greek alphabet

Greek character		Greek name	Roman equivalent
Α α	*Α α*	alpha	A a
Β β	*Β β*	beta	B b
Γ γ	*Γ γ*	gamma	G g
Δ δ	*Δ δ*	delta	D d
Ε ε, ϵ	*Ε ε, ϵ*	epsilon	Ĕ ĕ
Ζ ζ	*Ζ ζ*	zeta	Z z
Η η	*Η η*	eta	Ē ē
Θ ϑ, θ	*Θ ϑ, θ*	theta	Th th
Ι ι	*Ι ι*	iota	I i
Κ ϰ, κ	*Κ ϰ, κ*	kappa	K k
Λ λ	*Λ λ*	lambda	L l
Μ μ	*Μ μ*	mu	M m
Ν ν	*Ν ν*	nu	N n
Ξ ξ	*Ξ ξ*	xi	X x
Ο ο	*Ο ο*	omicron	Ŏ ŏ
Π π, ϖ	*Π π, ϖ*	pi	P p
Ρ ρ	*Ρ ϱ*	rho	R r
Σ σ, ς	*Σ σ, ς*	sigma	S s
Τ τ	*Τ τ*	tau	T t
Υ υ	*Υ υ*	upsilon	Y y
Φ φ, ϕ	*Φ φ, ϕ*	phi	Ph ph
Χ χ	*Χ χ*	chi	Ch ch
Ψ ψ	*Ψ ψ*	psi	Ps ps
Ω ω	*Ω ω*	omega	Ō ō

Prefixes and symbols for decimal multiples and submultiples of units[1]

Power of ten	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deca*	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

* Also 'deka'.
[1] Conference [illegible]

x	log x 0	1	2	3	4	5	6	7	8	9	Proportional parts 1	2	3	4	5	6	7	8
100	0000	0004	0009	0013	0017	0022	0026	0030	0035	0039	0	1	1	2	2	3	3	3
101	0043	0048	0052	0056	0060	0065	0069	0073	0077	0082	0	1	1	2	2	3	3	3
102	0086	0090	0095	0099	0103	0107	0111	0116	0120	0124	0	1	1	2	2	3	3	3
103	0128	0133	0137	0141	0145	0149	0154	0158	0162	0166	0	1	1	2	2	3	3	3
104	0170	0175	0179	0183	0187	0191	0195	0199	0204	0208	0	1	1	2	2	2	3	3
105	0212	0216	0220	0224	0228	0233	0237	0241	0245	0249	0	1	1	2	2	2	3	3
106	0253	0257	0261	0265	0269	0273	0278	0282	0286	0290	0	1	1	2	2	2	3	3
107	0294	0298	0302	0306	0310	0314	0318	0322	0326	0330	0	1	1	2	2	2	3	3
108	0334	0338	0342	0346	0350	0354	0358	0362	0366	0370	0	1	1	2	2	2	3	3
109	0374	0378	0382	0386	0390	0394	0398	0402	0406	0410	0	1	1	2	2	2	3	3
↓ 10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7
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52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3

log x	x										Proportional parts								
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	15	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

Natural Logarithms* 0.000—0.999

x	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.000	−∞	−6.90776	−6.21461	−5.80914	−5.52146	−5.29832	−5.11600	−4.96185	−4.82831	−4.71053
010	−4.60517	−4.50986	−4.42285	−4.34281	−4.26870	−4.19971	−4.13517	−4.07454	−4.01738	−3.96332
020	−3.91202	−3.86323	−3.81671	−3.77226	−3.72970	−3.68888	−3.64966	−3.61192	−3.57555	54046
030	50656	47377	44202	41125	38139	35241	32424	29684	27017	24419
040	21888	19418	17009	14656	12357	10109	07911	05761	03655	01593
0.050	−2.99573	−2.97593	−2.95651	−2.93746	−2.91877	−2.90042	−2.88240	−2.86470	−2.84731	−2.83022
060	81341	79688	78062	76462	74887	73337	71810	70306	68825	67365
070	65926	64508	63109	61730	60369	59027	57702	56395	55105	53831
080	52573	51331	50104	48891	47694	46510	45341	44185	43042	41912
090	40795	39690	38597	37516	36446	35388	34341	33304	32279	31264
0.100	−2.30259	−2.29263	−2.28278	−2.27303	−2.26336	−2.25379	−2.24432	−2.23493	−2.22562	−2.21641
110	20727	19823	18926	18037	17156	16282	15417	14558	13707	12863
120	12026	11196	10373	09557	08747	07944	07147	06357	05573	04794
130	04022	03256	02495	01741	00992	00248	−1.99510	−1.98777	−1.98050	−1.97328
140	−1.96611	−1.95900	−1.95193	−1.94491	−1.93794	−1.93102	92415	91732	91054	90381
0.150	−1.89712	−1.89048	−1.88387	−1.87732	−1.87080	−1.86433	−1.85790	−1.85151	−1.84516	−1.83885
160	83258	82635	82016	81401	80789	80181	79577	78976	78379	77786
170	77196	76609	76026	75446	74870	74297	73727	73161	72597	72037
180	71480	70926	70375	69827	69282	68740	68201	67665	67131	66601
190	66073	65548	65026	64507	63990	63476	62964	62455	61949	61445
0.200	−1.60944	−1.60445	−1.59949	−1.59455	−1.58964	−1.58475	−1.57988	−1.57504	−1.57022	−1.56542
210	56065	55590	55117	54646	54178	53712	53248	52786	52326	51868
220	51413	50959	50508	50058	49611	49165	48722	48281	47841	47403
230	46968	46534	46102	45672	45243	44817	44392	43970	43548	43129
240	42712	42296	41882	41469	41059	40650	40242	39837	39433	39030
0.250	−1.38629	−1.38230	−1.37833	−1.37437	−1.37042	−1.36649	−1.36258	−1.35868	−1.35480	−1.35093
260	34707	34323	33941	33560	33181	32803	32426	32051	31677	31304
270	30933	30564	30195	29828	29463	29098	28735	28374	28013	27654
280	27297	26940	26585	26231	25878	25527	25176	24827	24479	24133
290	23787	23443	23100	22758	22418	22078	21740	21402	21066	20731
0.300	−1.20397	−1.20065	−1.19733	−1.19402	−1.19073	−1.18744	−1.18417	−1.18091	−1.17766	−1.17441
310	17118	16796	16475	16155	15836	15518	15201	14885	14570	14256
320	13943	13631	13320	13010	12701	12393	12086	11780	11474	11170
330	10866	10564	10262	09961	09661	09362	09064	08767	08471	08176
340	07881	07587	07294	07002	06711	06421	06132	05843	05555	05268
0.350	−1.04982	−1.04697	−1.04412	−1.04129	−1.03846	−1.03564	−1.03282	−1.03002	−1.02722	−1.02443
360	02165	01888	01611	01335	01060	00786	00512	00239	−0.99967	−0.99696
370	−0.99425	−0.99155	−0.98886	−0.98618	−0.98350	−0.98083	−0.97817	−0.97551	97286	97022
380	96758	96496	96233	95972	95711	95451	95192	94933	94675	94418
390	94161	93905	93649	93395	93140	92887	92634	92382	92130	91879
0.400	−0.91629	−0.91379	−0.91130	−0.90882	−0.90634	−0.90387	−0.90140	−0.89894	−0.89649	−0.89404
410	89160	88916	88673	88431	88189	87948	87707	87467	87227	86988
420	86750	86512	86275	86038	85802	85567	85332	85097	84863	84630
430	84397	84165	83933	83702	83471	83241	83011	82782	82554	82326
440	82098	81871	81645	81419	81193	80968	80744	80520	80296	80073
0.450	−0.79851	−0.79629	−0.79407	−0.79186	−0.78966	−0.78746	−0.78526	−0.78307	−0.78089	−0.77871
460	77653	77436	77219	77003	76787	76572	76357	76143	75929	75715
470	75502	75290	75078	74866	74655	74444	74234	74024	73814	73605
480	73397	73189	72981	72774	72567	72361	72155	71949	71744	71539
490	71335	71131	70928	70725	70522	70320	70118	69917	69716	69515
0.500	−0.69315	−0.69115	−0.68916	−0.68717	−0.68518	−0.68320	−0.68122	−0.67924	−0.67727	−0.67531
510	67334	67139	66943	66748	66553	66359	66165	65971	65778	65585
520	65393	65201	65009	64817	64626	64436	64245	64055	63866	63677
530	63488	63299	63111	62923	62736	62549	62362	62176	61990	61804
540	61619	61434	61249	61065	60881	60697	60514	60331	60148	59966
0.550	−0.59784	−0.59602	−0.59421	−0.59240	−0.59059	−0.58879	−0.58699	−0.58519	−0.58340	−0.58161
560	57982	57803	57625	57448	57270	57093	56916	56740	56563	56387
570	56212	56037	55862	55687	55513	55339	55165	54991	54818	54645
580	54473	54300	54128	53957	53785	53614	53444	53273	53103	52933
590	52763	52594	52425	52256	52088	51919	51751	51584	51416	51249
0.600	−0.51083	−0.50916	−0.50750	−0.50584	−0.50418	−0.50253	−0.50088	−0.49923	−0.49758	−0.49594
610	49430	49266	49102	48939	48776	48613	48451	48289	48127	47965
620	47804	47642	47482	47321	47160	47000	46840	46681	46522	46362
630	46204	46045	45887	45728	45571	45413	45256	45099	44942	44785
640	44629	44473	44317	44161	44006	43850	43696	43541	43386	43232
0.650	−0.43078	−0.42925	−0.42771	−0.42618	−0.42465	−0.42312	−0.42159	−0.42007	−0.41855	−0.41703
660	41552	41400	41249	41098	40947	40797	40647	40497	40347	40197
670	40048	39899	39750	39601	39453	39304	39156	39008	38861	38713
680	38566	38419	38273	38126	37980	37834	37688	37542	37397	37251
690	37106	36962	36817	36673	36528	36384	36241	36097	35954	35810
0.700	−0.35667	−0.35525	−0.35382	−0.35240	−0.35098	−0.34956	−0.34814	−0.34672	−0.34531	−0.34390
710	34249	34108	33968	33827	33687	33547	33408	33268	33129	32989
720	32850	32712	32573	32435	32296	32158	32021	31883	31745	31608
730	31471	31334	31197	31061	30925	30788	30653	30517	30381	30246
740	30111	29975	29841	29706	29571	29437	29303	29169	29035	28902
0.750	−0.28768	−0.28635	−0.28502	−0.28369	−0.28236	−0.28104	−0.27971	−0.27839	−0.27707	−0.27575
760	27444	27312	27181	27050	26919	26788	26657	26527	26397	26266
770	26136	26007	25877	25748	25618	25489	25360	25231	25103	24974
780	24846	24718	24590	24462	24335	24207	24080	23953	23826	23699
790	23572	23446	23319	23193	23067	22941	22816	22690	22565	22439
0.800	−0.22314	−0.22189	−0.22065	−0.21940	−0.21816	−0.21691	−0.21567	−0.21443	−0.21319	−0.21196
810	21072	20949	20825	20702	20579	20457	20334	20212	20089	19967
820	19845	19723	19601	19480	19358	19237	19116	18995	18874	18754
830	18633	18513	18392	18272	18152	18032	17913	17793	17674	17554
840	17435	17316	17198	17079	16960	16842	16724	16605	16487	16370
0.850	−0.16252	−0.16134	−0.16017	−0.15900	−0.15782	−0.15665	−0.15548	−0.15432	−0.15315	−0.15199
860	15082	14966	14850	14734	14618	14503	14387	14272	14156	14041
870	13926	13811	13697	13582	13467	13353	13239	13125	13011	12897
880	12783	12670	12556	12443	12330	12217	12104	11991	11878	11766
890	11653	11541	11429	11317	11205	11093	10981	10870	10759	10647
0.900	−0.10536	−0.10425	−0.10314	−0.10203	−0.10093	−0.09982	−0.09872	−0.09761	−0.09651	−0.09541
910	09431	09321	09212	09102	08992	08883	08774	08665	08556	08447
920	08338	08230	08121	08013	07904	07796	07688	07580	07472	07365
930	07257	07150	07042	06935	06828	06721	06614	06507	06401	06294
940	06188	06081	05975	05869	05763	05657	05551	05446	05340	05235
0.950	−0.05129	−0.05024	−0.04919	−0.04814	−0.04709	−0.04604	−0.04500	−0.04395	−0.04291	−0.04186
960	04082	03978	03874	03770	03666	03563	03459	03356	03252	03149
970	03046	02943	02840	02737	02634	02532	02429	02327	02225	02122
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

x	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1.00	0.00000	0.00995	0.01980	0.02956	0.03922	0.04879	0.05827	0.06766	0.07696	0.08618
10	09531	10436	11333	12222	13103	13976	14842	15700	16551	17395
20	18232	19062	19885	20701	21511	22314	23111	23902	24686	25464
30	26236	27003	27763	28518	29267	30010	30748	31481	32208	32930
40	33647	34359	35066	35767	36464	37156	37844	38526	39204	39878
1.50	0.40547	0.41211	0.41871	0.42527	0.43178	0.43825	0.44469	0.45108	0.45742	0.46373
60	47000	47623	48243	48858	49470	50078	50682	51282	51879	52473
70	53063	53649	54232	54812	55389	55962	56531	57098	57661	58222
80	58779	59333	59884	60432	60977	61519	62058	62594	63127	63658
90	64185	64710	65233	65752	66269	66783	67294	67803	68310	68813
2.00	0.69315	0.69813	0.70310	0.70804	0.71295	0.71784	0.72271	0.72755	0.73237	0.73716
10	74194	74669	75142	75612	76081	76547	77011	77473	77932	78390
20	78846	79299	79751	80200	80648	81093	81536	81978	82418	82855
30	83291	83725	84157	84587	85015	85442	85866	86289	86710	87129
40	87547	87963	88377	88789	89200	89609	90016	90422	90826	91228
2.50	0.91629	0.92028	0.92426	0.92822	0.93216	0.93609	0.94001	0.94391	0.94779	0.95166
60	95551	95935	96317	96698	97078	97456	97833	98208	98582	98954
70	99325	99695	1.00063	1.00430	1.00796	1.01160	1.01523	1.01885	1.02245	1.02604
80	1.02962	1.03318	03674	04028	04380	04732	05082	05431	05779	06126
90	06471	06815	07158	07500	07841	08181	08519	08856	09192	09527
3.00	1.09861	1.10194	1.10526	1.10856	1.11186	1.11514	1.11841	1.12168	1.12493	1.12817
10	13140	13462	13783	14103	14422	14740	15057	15373	15688	16002
20	16315	16627	16938	17248	17557	17865	18173	18479	18784	19089
30	19392	19695	19996	20297	20597	20896	21194	21491	21788	22083
40	22378	22671	22964	23256	23547	23837	24127	24415	24703	24990
3.50	1.25276	1.25562	1.25846	1.26130	1.26413	1.26695	1.26976	1.27257	1.27536	1.27815
60	28093	28371	28647	28923	29198	29473	29746	30019	30291	30563
70	30833	31103	31372	31641	31909	32176	32442	32708	32972	33237
80	33500	33763	34025	34286	34547	34807	35067	35325	35584	35841
90	36098	36354	36609	36864	37118	37372	37624	37877	38128	38379
4.00	1.38629	1.38879	1.39128	1.39377	1.39624	1.39872	1.40118	1.40364	1.40610	1.40854
10	41099	41342	41585	41828	42070	42311	42552	42792	43031	43270
20	43508	43746	43984	44220	44456	44692	44927	45161	45395	45629
30	45862	46094	46326	46557	46787	47018	47247	47476	47705	47933
40	48160	48387	48614	48840	49065	49290	49515	49739	49962	50185
4.50	1.50408	1.50630	1.50851	1.51072	1.51293	1.51513	1.51732	1.51951	1.52170	1.52388
60	52606	52823	53039	53256	53471	53687	53902	54116	54330	54543
70	54756	54969	55181	55393	55604	55814	56025	56235	56444	56653
80	56862	57070	57277	57485	57691	57898	58104	58309	58515	58719
90	58924	59127	59331	59534	59737	59939	60141	60342	60543	60744
5.00	1.60944	1.61144	1.61343	1.61542	1.61741	1.61939	1.62137	1.62334	1.62531	1.62728
10	62924	63120	63315	63511	63705	63900	64094	64287	64481	64673
20	64866	65058	65250	65441	65632	65823	66013	66203	66393	66582
30	66771	66959	67147	67335	67523	67710	67896	68083	68269	68455
40	68640	68825	69010	69194	69378	69562	69745	69928	70111	70293
5.50	1.70475	1.70656	1.70838	1.71019	1.71199	1.71380	1.71560	1.71740	1.71919	1.72098
60	72277	72455	72633	72811	72988	73166	73342	73519	73695	73871
70	74047	74222	74397	74572	74746	74920	75094	75267	75440	75613
80	75786	75958	76130	76302	76473	76644	76815	76985	77156	77326
90	77495	77665	77834	78002	78171	78339	78507	78675	78842	79009
6.00	1.79176	1.79342	1.79509	1.79675	1.79840	1.80006	1.80171	1.80336	1.80500	1.80665
10	80829	80993	81156	81319	81482	81645	81808	81970	82132	82294
20	82455	82616	82777	82938	83098	83258	83418	83578	83737	83896
30	84055	84214	84372	84530	84688	84845	85003	85160	85317	85473
40	85630	85786	85942	86097	86253	86408	86563	86718	86872	87026
6.50	1.87180	1.87334	1.87487	1.87641	1.87794	1.87947	1.88099	1.88251	1.88403	1.88555
60	88707	88858	89010	89160	89311	89462	89612	89762	89912	90061
70	90211	90360	90509	90658	90806	90954	91102	91250	91398	91545
80	91692	91839	91986	92132	92279	92425	92571	92716	92862	93007
90	93152	93297	93442	93586	93730	93874	94018	94162	94305	94448
7.00	1.94591	1.94734	1.94876	1.95019	1.95161	1.95303	1.95445	1.95586	1.95727	1.95869
10	96009	96150	96291	96431	96571	96711	96851	96991	97130	97269
20	97408	97547	97685	97824	97962	98100	98238	98376	98513	98650
30	98787	98924	99061	99198	99334	99470	99606	99742	99877	2.00013
40	2.00148	2.00283	2.00418	2.00553	2.00687	2.00821	2.00956	2.01089	2.01223	01357
7.50	2.01490	2.01624	2.01757	2.01890	2.02022	2.02155	2.02287	2.02419	2.02551	2.02683
60	02815	02946	03078	03209	03340	03471	03601	03732	03862	03992
70	04122	04252	04381	04511	04640	04769	04898	05027	05156	05284
80	05412	05540	05668	05796	05924	06051	06179	06306	06433	06560
90	06686	06813	06939	07065	07191	07317	07443	07568	07694	07819
8.00	2.07944	2.08069	2.08194	2.08318	2.08443	2.08567	2.08691	2.08815	2.08939	2.09063
10	09186	09310	09433	09556	09679	09802	09924	10047	10169	10291
20	10413	10535	10657	10779	10900	11021	11142	11263	11384	11505
30	11626	11746	11866	11986	12106	12226	12346	12465	12585	12704
40	12823	12942	13061	13180	13298	13417	13535	13653	13771	13889
8.50	2.14007	2.14124	2.14242	2.14359	2.14476	2.14593	2.14710	2.14827	2.14943	2.15060
60	15176	15292	15409	15524	15640	15756	15871	15987	16102	16217
70	16332	16447	16562	16677	16791	16905	17020	17134	17248	17361
80	17475	17589	17702	17816	17929	18042	18155	18267	18380	18493
90	18605	18717	18830	18942	19054	19165	19277	19389	19500	19611
9.00	2.19722	2.19834	2.19944	2.20055	2.20166	2.20276	2.20387	2.20497	2.20607	2.20717
10	20827	20937	21047	21157	21266	21375	21485	21594	21703	21812
20	21920	22029	22138	22246	22354	22462	22570	22678	22786	22894
30	23001	23109	23216	23324	23431	23538	23645	23751	23858	23965
40	24071	24177	24284	24390	24496	24601	24707	24813	24918	25024
9.50	2.25129	2.25234	2.25339	2.25444	2.25549	2.25654	2.25759	2.25863	2.25968	2.26072
60	26176	26280	26384	26488	26592	26696	26799	26903	27006	27109
70	27213	27316	27419	27521	27624	27727	27829	27932	28034	28136
80	28238	28340	28442	28544	28646	28747	28849	28950	29051	29152
90	29253	29354	29455	29556	29657	29757	29858	29958	30058	30158

* To find the natural logarithm ($\log_e$) of a number which is a power of ten less or greater than a number given in the table if the number concerned is *less*, e g, $^1/_{10}$ (10^{-1}), $^1/_{100}$ (10^{-2}), $^1/_{1000}$ (10^{-3}), etc, *subtract* from the given logarithm $\log_e 10$, $2 \log_e 10$, $3 \log_e 10$, etc, if the number concerned is *greater*, e g, 10 times (10^1), 100 times (10^2), 1000 times (10^3), etc, *add* to the given logarithm $\log_e 10$, $2 \log_e 10$, $3 \log_e 10$, etc. Examples $\log_e 0.02 = \log_e 0.2 - \log_e 10$, $\log_e 2000 = \log_e 200 + \log_e 10$

N	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10.0	2.30259	2.31254	2.32239	2.33214	2.34181	2.35138	2.36085	2.37024	2.37955	2.38876
11.0	39790	40695	41591	42480	43361	44235	45101	45959	46810	47654
12.0	48491	49321	50144	50960	51770	52573	53370	54160	54945	55723
13.0	56495	57261	58022	58776	59525	60269	61007	61740	62467	63189
14.0	63906	64617	65324	66026	66723	67415	68102	68785	69463	70136
15.0	2.70805	2.71469	2.72130	2.72785	2.73437	2.74084	2.74727	2.75366	2.76001	2.76632
16.0	77259	77882	78501	79117	79728	80336	80940	81541	82138	82731
17.0	83321	83908	84491	85071	85647	86220	86790	87356	87920	88480
18.0	89037	89591	90142	90690	91235	91777	92316	92852	93386	93916
19.0	94444	94969	95491	96011	96527	97041	97553	98062	98568	99072
20.0	2.99573	3.00072	3.00568	3.01062	3.01553	3.02042	3.02529	3.03013	3.03495	3.03975
21.0	3.04452	04927	05400	05871	06339	06805	07269	07731	08191	08649
22.0	09104	09558	10009	10459	10906	11352	11795	12236	12676	13114
23.0	13549	13983	14415	14845	15274	15700	16125	16548	16969	17388
24.0	17805	18221	18635	19048	19458	19867	20275	20680	21084	21487
25.0	3.21888	3.22287	3.22684	3.23080	3.23475	3.23868	3.24259	3.24649	3.25037	3.25424
26.0	25810	26194	26576	26957	27336	27714	28091	28466	28840	29213
27.0	29584	29953	30322	30689	31054	31419	31782	32143	32504	32863
28.0	33220	33577	33932	34286	34639	34990	35341	35690	36038	36384
29.0	36730	37074	37417	37759	38099	38439	38777	39115	39451	39786
30.0	3.40120	3.40453	3.40784	3.41115	3.41444	3.41773	3.42100	3.42426	3.42751	3.43076
31.0	43399	43721	44042	44362	44681	44999	45316	45632	45947	46261
32.0	46574	46886	47197	47507	47816	48124	48431	48738	49043	49347
33.0	49651	49953	50255	50556	50856	51155	51453	51750	52046	52342
34.0	52636	52930	53223	53515	53806	54096	54385	54674	54962	55249
35.0	3.55535	3.55820	3.56105	3.56388	3.56671	3.56953	3.57235	3.57515	3.57795	3.58074
36.0	58352	58629	58906	59182	59457	59731	60005	60278	60550	60821
37.0	61092	61362	61631	61899	62167	62434	62700	62966	63231	63495
38.0	63759	64021	64284	64545	64806	65066	65325	65584	65842	66099
39.0	66356	66612	66868	67122	67377	67630	67883	68135	68387	68638
40.0	3.68888	3.69138	3.69387	3.69635	3.69883	3.70130	3.70377	3.70623	3.70868	3.71113
41.0	71357	71601	71844	72086	72328	72569	72810	73050	73290	73529
42.0	73767	74005	74242	74479	74715	74950	75185	75420	75654	75887
43.0	76120	76352	76584	76815	77046	77276	77506	77735	77963	78191
44.0	78419	78646	78872	79098	79324	79549	79773	79997	80221	80444
45.0	3.80666	3.80888	3.81110	3.81331	3.81551	3.81771	3.81991	3.82210	3.82428	3.82647
46.0	82864	83081	83298	83514	83730	83945	84160	84374	84588	84802
47.0	85015	85227	85439	85651	85862	86073	86283	86493	86703	86912
48.0	87120	87328	87536	87743	87950	88156	88362	88568	88773	88978
49.0	89182	89386	89589	89792	89995	90197	90399	90600	90801	91002
50.0	3.91202	3.91402	3.91602	3.91801	3.91999	3.92197	3.92395	3.92593	3.92790	3.92986
51.0	93183	93378	93574	93769	93964	94158	94352	94546	94739	94932
52.0	95124	95316	95508	95700	95891	96081	96272	96462	96651	96840
53.0	97029	97218	97406	97594	97781	97968	98155	98341	98527	98713
54.0	98898	99083	99268	99452	99636	99820	4.00003	4.00186	4.00369	4.00551
55.0	4.00733	4.00915	4.01096	4.01277	4.01458	4.01638	4.01818	4.01998	4.02177	4.02356
56.0	02535	02714	02892	03069	03247	03424	03601	03777	03954	04130
57.0	04305	04480	04655	04830	05004	05178	05352	05526	05699	05872
58.0	06044	06217	06389	06560	06732	06903	07073	07244	07414	07584
59.0	07754	07923	08092	08261	08429	08598	08766	08933	09101	09268
60.0	4.09434	4.09601	4.09767	4.09933	4.10099	4.10264	4.10429	4.10594	4.10759	4.10923
61.0	11087	11251	11415	11578	11741	11904	12066	12228	12390	12552
62.0	12713	12875	13036	13196	13357	13517	13677	13836	13996	14155
63.0	14313	14472	14630	14789	14946	15104	15261	15418	15575	15732
64.0	15888	16044	16200	16356	16511	16667	16821	16976	17131	17285
65.0	4.17439	4.17592	4.17746	4.17899	4.18052	4.18205	4.18358	4.18510	4.18662	4.18814
66.0	18965	19117	19268	19419	19570	19720	19870	20020	20170	20320
67.0	20469	20618	20767	20916	21065	21213	21361	21509	21656	21804
68.0	21951	22098	22244	22391	22537	22683	22829	22975	23120	23266
69.0	23411	23555	23700	23844	23989	24133	24276	24420	24563	24707
70.0	4.24850	4.24992	4.25135	4.25277	4.25419	4.25561	4.25703	4.25845	4.25986	4.26127
71.0	26268	26409	26549	26690	26830	26970	27110	27249	27388	27528
72.0	27667	27805	27944	28082	28221	28359	28496	28634	28772	28909
73.0	29046	29183	29320	29456	29592	29729	29865	30000	30136	30271
74.0	30407	30542	30676	30811	30946	31080	31214	31348	31482	31615
75.0	4.31749	4.31882	4.32015	4.32149	4.32281	4.32413	4.32546	4.32678	4.32810	4.32942
76.0	33073	33205	33336	33467	33598	33729	33860	33990	34120	34251
77.0	34381	34510	34640	34769	34899	35028	35157	35286	35414	35543
78.0	35671	35800	35927	36055	36182	36310	36437	36564	36691	36818
79.0	36945	37071	37198	37324	37450	37576	37701	37827	37952	38078
80.0	4.38203	4.38328	4.38452	4.38577	4.38701	4.38826	4.38950	4.39074	4.39198	4.39321
81.0	39445	39568	39692	39815	39938	40060	40183	40305	40428	40550
82.0	40672	40794	40916	41037	41159	41280	41401	41522	41643	41764
83.0	41884	42004	42125	42245	42365	42485	42604	42724	42843	42963
84.0	43082	43201	43319	43438	43557	43675	43793	43912	44030	44147
85.0	4.44265	4.44383	4.44500	4.44617	4.44735	4.44852	4.44969	4.45085	4.45202	4.45318
86.0	45435	45551	45667	45783	45899	46014	46130	46245	46361	46476
87.0	46591	46706	46820	46935	47050	47164	47278	47392	47506	47620
88.0	47734	47847	47961	48074	48187	48300	48413	48526	48639	48751
89.0	48864	48976	49088	49200	49312	49424	49536	49647	49758	49870
90.0	4.49981	4.50092	4.50203	4.50314	4.50424	4.50535	4.50645	4.50756	4.50866	4.50976
91.0	51086	51196	51305	51415	51525	51634	51743	51852	51961	52070
92.0	52179	52287	52396	52504	52613	52721	52829	52937	53045	53152
93.0	53260	53367	53475	53582	53689	53796	53903	54010	54116	54223
94.0	54329	54436	54542	54648	54754	54860	54966	55071	55177	55282
95.0	4.55388	4.55493	4.55598	4.55703	4.55808	4.55913	4.56017	4.56122	4.56226	4.56331
96.0	56435	56539	56643	56747	56851	56954	57058	57161	57265	57368
97.0	57471	57574	57677	57780	57883	57985	58088	58190	58292	58395
98.0	58497	58599	58701	58802	58904	59006	59107	59208	59310	59411
99.0	59512	59613	59714	59815	59915	60016	60116	60217	60317	60417

* To find the natural logarithm ($\log_e$) of a number which is a power of ten less or greater than a number given in the table: if the number concerned is *less*, e.g., $^1/_{10}$ (10^{-1}), $^1/_{100}$ (10^{-2}), $^1/_{1000}$ (10^{-3}), etc., *subtract* from the given logarithm $\log_e 10$, $2 \log_e 10$, $3 \log_e 10$, etc.; if the number concerned is *greater*, e.g., 10 times (10^1), 100 times (10^2), 1000 times (10^3), etc., *add* to the given logarithm $\log_e 10$, $2 \log_e 10$, $3 \log_e 10$, etc. Examples: $\log_e 0.02 = \log_e 0.2 - \log_e 10$; $\log_e 2000 = \log_e 200 + \log_e 10$.

x	0	1	2	3	4	5	6	7	8	9
00	∞	0 00000	0 69315	1 09861	1 38629	1 60944	1.79176	1 94591	2.07944	2.19722
10	2 30259	2 39790	2.48491	2.56495	2.63906	2.70805	2.77259	2.83321	89037	94444
20	99573	3 04452	3 09104	3 13549	3 17805	3 21888	3 25810	3 29584	3 33220	3.36730
30	3 40120	43399	46574	49651	52636	55535	58352	61092	63759	66356
40	68888	71357	73767	76120	78419	80666	82864	85015	87120	89182
50	3 91202	3 93183	3 95124	3 97029	3 98898	4 00733	4 02535	4 04305	4 06044	4 07754
60	4 09434	4 11087	4 12713	4 14313	4 15888	17439	18965	20469	21951	23411
70	24850	26268	27667	29046	30407	31749	33073	34381	35671	36945
80	38203	39445	40672	41884	43082	44265	45435	46591	47734	48864
90	49981	51086	52179	53260	54329	55388	56435	57471	58497	59512
100	4 60517	4 61512	4 62497	4 63473	4 64439	4 65396	4 66344	4 67283	4 68213	4 69135
110	70048	70953	71850	72739	73620	74493	75359	76217	77068	77912
120	78749	79579	80402	81218	82028	82831	83628	84419	85203	85981
130	86753	87520	88280	89035	89784	90527	91265	91998	92725	93447
140	94164	94876	95583	96284	96981	97673	98361	99043	99721	5.00395
150	5 01064	5 01728	5 02388	5 03044	5 03695	5 04343	5 04986	5 05625	5 06260	5 06890
160	07517	08140	08760	09375	09987	10595	11199	11799	12396	12990
170	13580	14166	14749	15329	15906	16479	17048	17615	18178	18739
180	19296	19850	20401	20949	21494	22036	22575	23111	23644	24175
190	24702	25227	25750	26269	26786	27300	27811	28320	28827	29330
200	5 29832	5 30330	5 30827	5 31321	5 31812	5 32301	5 32788	5 33272	5.33754	5 34233
210	34711	35186	35659	36129	36598	37064	37528	37990	38450	38907
220	39363	39816	40268	40717	41165	41610	42053	42495	42935	43372
230	43808	44242	44674	45104	45532	45959	46383	46806	47227	47646
240	48064	48480	48894	49306	49717	50126	50533	50939	51343	51745
250	5 52146	5 52545	5 52943	5 53339	5 53733	5 54126	5 54518	5 54908	5 55296	5 55683
260	56068	56452	56834	57215	57595	57973	58350	58725	59099	59471
270	59842	60212	60580	60947	61313	61677	62040	62402	62762	63121
280	63479	63835	64191	64545	64897	65249	65599	65948	66296	66643
290	66988	67332	67675	68017	68358	68698	69036	69373	69709	70044
300	5 70378	5 70711	5 71043	5 71373	5 71703	5 72031	5 72359	5 72685	5 73010	5 73334
310	73657	73979	74300	74620	74939	75257	75574	75890	76205	76519
320	76832	77144	77455	77765	78074	78383	78690	78996	79301	79606
330	79909	80212	80513	80814	81114	81413	81711	82008	82305	82600
340	82895	83188	83481	83773	84064	84354	84644	84932	85220	85507
350	5 85793	5 86079	5 86363	5 86647	5 86930	5 87212	5 87493	5 87774	5 88053	5 88332
360	88610	88889	89164	89440	89715	89990	90263	90536	90808	91080
370	91350	91620	91889	92158	92426	92693	92959	93225	93489	93754
380	94017	94280	94542	94803	95064	95324	95584	95842	96101	96358
390	96615	96871	97126	97381	97635	97889	98141	98394	98645	98896
400	5 99146	5 99396	5 99645	5 99894	6 00141	6 00389	6 00635	6 00881	6 01127	6 01372
410	6 01616	6 01859	6 02102	6 02345	02587	02828	03069	03309	03548	03787
420	04025	04263	04501	04737	04973	05209	05444	05678	05912	06146
430	06379	06611	06843	07074	07304	07535	07764	07993	08222	08450
440	08677	08904	09131	09357	09582	09807	10032	10256	10479	10702
450	6 10925	6 11147	6 11368	6 11589	6 11810	6 12030	6 12249	6 12468	6 12687	6 12905
460	13123	13340	13556	13773	13988	14204	14419	14633	14847	15060
470	15273	15486	15698	15910	16121	16331	16542	16752	16961	17170
480	17379	17587	17794	18002	18208	18415	18621	18826	19032	19236
490	19441	19644	19848	20051	20254	20456	20658	20859	21060	21261
500	6 21461	6 21661	6 21860	6 22059	6 22258	6 22456	6 22654	6 22851	6 23048	6 23245
510	23441	23637	23832	24028	24222	24417	24611	24804	24998	25190
520	25383	25575	25767	25958	26149	26340	26530	26720	26910	27099
530	27288	27476	27664	27852	28040	28227	28413	28600	28786	28972
540	29157	29342	29527	29711	29895	30079	30262	30445	30628	30810
550	6 30992	6 31173	6 31355	6 31536	6 31716	6 31897	6 32077	6 32257	6 32436	6 32615
560	32794	32972	33150	33328	33505	33683	33859	34036	34212	34388
570	34564	34739	34914	35089	35263	35437	35611	35784	35957	36130
580	36303	36475	36647	36819	36990	37161	37332	37502	37673	37843
590	38012	38182	38351	38519	38688	38856	39024	39192	39359	39526
600	6 39693	6 39859	6 40026	6 40192	6 40357	6 40523	6 40688	6 40853	6 41017	6 41182
610	41346	41510	41673	41836	41999	42162	42325	42487	42649	42811
620	42972	43133	43294	43455	43615	43775	43935	44095	44254	44413
630	44572	44731	44889	45047	45205	45362	45520	45677	45834	45990
640	46147	46303	46459	46614	46770	46925	47080	47235	47389	47543
650	6 47697	6 47851	6 48004	6 48158	6 48311	6 48464	6 48616	6 48768	6 48920	6 49072
660	49224	49375	49527	49677	49828	49979	50129	50279	50429	50578
670	50728	50877	51026	51175	51323	51471	51619	51767	51915	52062
680	52209	52356	52503	52649	52796	52942	53088	53233	53379	53524
690	53669	53814	53959	54103	54247	54391	54535	54679	54822	54965
700	6 55108	6 55251	6 55393	6 55536	6 55678	6 55820	6 55962	6 56103	6 56244	6 56386
710	56526	56667	56808	56948	57088	57228	57368	57508	57647	57786
720	57925	58064	58203	58341	58479	58617	58755	58893	59030	59167
730	59304	59441	59578	59715	59851	59987	60123	60259	60394	60530
740	60665	60800	60935	61070	61204	61338	61473	61607	61740	61874
750	6 62007	6 62141	6 62274	6 62407	6 62539	6 62672	6 62804	6 62936	6 63068	6 63200
760	63332	63463	63595	63726	63857	63988	64118	64249	64379	64509
770	64639	64769	64898	65028	65157	65286	65415	65544	65673	65801
780	65929	66058	66185	66313	66441	66568	66696	66823	66950	67077
790	67203	67330	67456	67582	67708	67834	67960	68085	68211	68336
800	6 68461	6 68586	6 68711	6 68835	6 68960	6 69084	6 69208	6 69332	6 69456	6 69580
810	69703	69827	69950	70073	70196	70319	70441	70564	70686	70808
820	70930	71052	71174	71296	71417	71538	71659	71780	71901	72022
830	72143	72263	72383	72503	72623	72743	72863	72982	73102	73221
840	73340	73459	73578	73697	73815	73934	74052	74170	74288	74406
850	6 74524	6 74641	6 74759	6 74876	6 74993	6 75110	6 75227	6 75344	6 75460	6 75577
860	75693	75809	75926	76041	76157	76273	76388	76504	76619	76734
870	76849	76964	77079	77194	77308	77422	77537	77651	77765	77878
880	77992	78106	78219	78333	78446	78559	78672	78784	78897	79010
890	79122	79234	79347	79459	79571	79682	79794	79906	80017	80128
900	6 80239	6 80351	6 80461	6 80572	6 80683	6 80793	6 80904	6 81014	6 81124	6 81235
910	81344	81454	81564	81674	81783	81892	82002	82111	82220	82329
920	82437	82546	82655	82763	82871	82979	83087	83195	83303	83411
930	83518	83626	83733	83841	83948	84055	84162	84268	84375	84482
940	84588	84694	84801	84907	85013	85118	85224	85330	85435	85541
950	6 85646	6 85751	6 85857	6 85961	6 86066	6 86171	6 86276	6 86380	6 86485	6 86589
960	86693	86797	86901	87005	87109	87213	87316	87420	87523	87626
970	87730	87833	87936	88038	88141	88244	88346	88449	88551	88653
980	88755	88857	88959	89061	89163	89264	89366	89467	[illegible]	[illegible]
990	89770	89871	89972	90073	90174	90274	90375	[illegible]	[illegible]	[illegible]

x	e^x	$\log_{10}(e^x)$	e^{-x}	x	e^x	$\log_{10}(e^x)$	e^{-x}	x	e^x	$\log_{10}(e^x)$	e^{-x}
0.00	1.0000	0.00000	1.000000	1.00	2.7183	0.43429	0.367879	2.00	7.3891	0.86859	0.135335
0.01	1.0101	00434	0.990050	1.01	2.7456	43864	364219	2.01	7.4633	87293	133989
0.02	1.0202	00869	980199	1.02	2.7732	44298	360595	2.02	7.5383	87727	132655
0.03	1.0305	01303	970446	1.03	2.8011	44732	357007	2.03	7.6141	88162	131336
0.04	1.0408	01737	960789	1.04	2.8292	45167	353455	2.04	7.6906	88596	130029
0.05	1.0513	0.02171	0.951229	1.05	2.8577	0.45601	0.349938	2.05	7.7679	0.89030	0.128735
0.06	1.0618	02606	941765	1.06	2.8864	46035	346456	2.06	7.8460	89465	127454
0.07	1.0725	03040	932394	1.07	2.9154	46470	343009	2.07	7.9248	89899	126186
0.08	1.0833	03474	923116	1.08	2.9447	46904	339596	2.08	8.0045	90333	124930
0.09	1.0942	03909	913931	1.09	2.9743	47338	336216	2.09	8.0849	90768	123687
0.10	1.1052	0.04343	0.904837	1.10	3.0042	0.47772	0.332871	2.10	8.1662	0.91202	0.122456
0.11	1.1163	04777	895834	1.11	3.0344	48207	329559	2.11	8.2482	91636	121238
0.12	1.1275	05212	886920	1.12	3.0649	48641	326280	2.12	8.3311	92070	120032
0.13	1.1388	05646	878095	1.13	3.0957	49075	323033	2.13	8.4149	92505	118837
0.14	1.1503	06080	869358	1.14	3.1268	49510	319819	2.14	8.4994	92939	117655
0.15	1.1618	0.06514	0.860708	1.15	3.1582	0.49944	0.316637	2.15	8.5849	0.93373	0.116484
0.16	1.1735	06949	852144	1.16	3.1899	50378	313486	2.16	8.6711	93808	115325
0.17	1.1853	07383	843665	1.17	3.2220	50812	310367	2.17	8.7583	94242	114178
0.18	1.1972	07817	835270	1.18	3.2544	51247	307279	2.18	8.8463	94676	113042
0.19	1.2092	08252	826959	1.19	3.2871	51681	304221	2.19	8.9352	95110	111917
0.20	1.2214	0.08686	0.818731	1.20	3.3201	0.52115	0.301194	2.20	9.0250	0.95545	0.110803
0.21	1.2337	09120	810584	1.21	3.3535	52550	298197	2.21	9.1157	95979	109701
0.22	1.2461	09554	802519	1.22	3.3872	52984	295230	2.22	9.2073	96413	108609
0.23	1.2586	09989	794534	1.23	3.4212	53418	292293	2.23	9.2999	96848	107528
0.24	1.2712	10423	786628	1.24	3.4556	53853	289384	2.24	9.3933	97282	106459
0.25	1.2840	0.10857	0.778801	1.25	3.4903	0.54287	0.286505	2.25	9.4877	0.97716	0.105399
0.26	1.2969	11292	771052	1.26	3.5254	54721	283654	2.26	9.5831	98151	104350
0.27	1.3100	11726	763379	1.27	3.5609	55155	280832	2.27	9.6794	98585	103312
0.28	1.3231	12160	755784	1.28	3.5966	55590	278037	2.28	9.7767	99019	102284
0.29	1.3364	12595	748264	1.29	3.6328	56024	275271	2.29	9.8749	99453	101266
0.30	1.3499	0.13029	0.740818	1.30	3.6693	0.56458	0.272532	2.30	9.9742	0.99888	0.100259
0.31	1.3634	13463	733447	1.31	3.7062	56893	269820	2.31	10.074	1.00322	099261
0.32	1.3771	13897	726149	1.32	3.7434	57327	267135	2.32	10.176	00756	098274
0.33	1.3910	14332	718924	1.33	3.7810	57761	264477	2.33	10.278	01191	097296
0.34	1.4049	14766	711770	1.34	3.8190	58195	261846	2.34	10.381	01625	096328
0.35	1.4191	0.15200	0.704688	1.35	3.8574	0.58630	0.259240	2.35	10.486	1.02059	0.095369
0.36	1.4333	15635	697676	1.36	3.8962	59064	256661	2.36	10.591	02493	094420
0.37	1.4477	16069	690734	1.37	3.9354	59498	254107	2.37	10.697	02928	093481
0.38	1.4623	16503	683861	1.38	3.9749	59933	251579	2.38	10.805	03362	092551
0.39	1.4770	16937	677057	1.39	4.0149	60367	249075	2.39	10.913	03796	091630
0.40	1.4918	0.17372	0.670320	1.40	4.0552	0.60801	0.246597	2.40	11.023	1.04231	0.090718
0.41	1.5068	17806	663650	1.41	4.0960	61236	244143	2.41	11.134	04665	089815
0.42	1.5220	18240	657047	1.42	4.1371	61670	241714	2.42	11.246	05099	088922
0.43	1.5373	18675	650509	1.43	4.1787	62104	239309	2.43	11.359	05534	088037
0.44	1.5527	19109	644036	1.44	4.2207	62538	236928	2.44	11.473	05968	087161
0.45	1.5683	0.19543	0.637628	1.45	4.2631	0.62973	0.234570	2.45	11.588	1.06402	0.086294
0.46	1.5841	19978	631284	1.46	4.3060	63407	232236	2.46	11.705	06836	085435
0.47	1.6000	20412	625002	1.47	4.3492	63841	229925	2.47	11.822	07271	084585
0.48	1.6161	20846	618783	1.48	4.3929	64276	227638	2.48	11.941	07705	083743
0.49	1.6323	21280	612626	1.49	4.4371	64710	225373	2.49	12.061	08139	082910
0.50	1.6487	0.21715	0.606531	1.50	4.4817	0.65144	0.223130	2.50	12.182	1.08574	0.082085
0.51	1.6653	22149	600496	1.51	4.5267	65578	220910	2.51	12.305	09008	081268
0.52	1.6820	22583	594521	1.52	4.5722	66013	218712	2.52	12.429	09442	080460
0.53	1.6989	23018	588605	1.53	4.6182	66447	216536	2.53	12.554	09877	079659
0.54	1.7160	23452	582748	1.54	4.6646	66881	214381	2.54	12.680	10311	078866
0.55	1.7333	0.23886	0.576950	1.55	4.7115	0.67316	0.212248	2.55	12.807	1.10745	0.078082
0.56	1.7507	24320	571209	1.56	4.7588	67750	210136	2.56	12.936	11179	077305
0.57	1.7683	24755	565525	1.57	4.8066	68184	208045	2.57	13.066	11614	076536
0.58	1.7860	25189	559898	1.58	4.8550	68619	205975	2.58	13.197	12048	075774
0.59	1.8040	25623	554327	1.59	4.9037	69053	203926	2.59	13.330	12482	075020
0.60	1.8221	0.26058	0.548812	1.60	4.9530	0.69487	0.201897	2.60	13.464	1.12917	0.074274
0.61	1.8404	26492	543351	1.61	5.0028	69921	199888	2.61	13.599	13351	073535
0.62	1.8589	26926	537944	1.62	5.0531	70356	197899	2.62	13.736	13785	072803
0.63	1.8776	27361	532592	1.63	5.1039	70790	195930	2.63	13.874	14219	072078
0.64	1.8965	27795	527292	1.64	5.1552	71224	193980	2.64	14.013	14654	071361
0.65	1.9155	0.28229	0.522046	1.65	5.2070	0.71659	0.192050	2.65	14.154	1.15088	0.070651
0.66	1.9348	28663	516851	1.66	5.2593	72093	190139	2.66	14.296	15522	069948
0.67	1.9542	29098	511709	1.67	5.3122	72527	188247	2.67	14.440	15957	069252
0.68	1.9739	29532	506617	1.68	5.3656	72961	186374	2.68	14.585	16391	068563
0.69	1.9937	29966	501576	1.69	5.4195	73396	184520	2.69	14.732	16825	067881
0.70	2.0138	0.30401	0.496585	1.70	5.4739	0.73830	0.182684	2.70	14.880	1.17260	0.067206
0.71	2.0340	30835	491644	1.71	5.5290	74264	180866	2.71	15.029	17694	066537
0.72	2.0544	31269	486752	1.72	5.5845	74699	179066	2.72	15.180	18128	065875
0.73	2.0751	31703	481909	1.73	5.6407	75133	177284	2.73	15.333	18562	065219
0.74	2.0959	32138	477114	1.74	5.6973	75567	175520	2.74	15.487	18997	064570
0.75	2.1170	0.32572	0.472367	1.75	5.7546	0.76002	0.173774	2.75	15.643	1.19431	0.063928
0.76	2.1383	33006	467666	1.76	5.8124	76436	172045	2.76	15.800	19865	063292
0.77	2.1598	33441	463013	1.77	5.8709	76870	170333	2.77	15.959	20300	062662
0.78	2.1815	33875	458406	1.78	5.9299	77304	168638	2.78	16.119	20734	062039
0.79	2.2034	34309	453845	1.79	5.9895	77739	166960	2.79	16.281	21168	061421
0.80	2.2255	0.34744	0.449329	1.80	6.0496	0.78173	0.165299	2.80	16.445	1.21602	0.060810
0.81	2.2479	35178	444858	1.81	6.1104	78607	163654	2.81	16.610	22037	060205
0.82	2.2705	35612	440432	1.82	6.1719	79042	162026	2.82	16.777	22471	059606
0.83	2.2933	36046	436049	1.83	6.2339	79476	160414	2.83	16.945	22905	059013
0.84	2.3164	36481	431711	1.84	6.2965	79910	158817	2.84	17.116	23340	058426
0.85	2.3396	0.36915	0.427415	1.85	6.3598	0.80344	0.157237	2.85	17.288	1.23774	0.057844
0.86	2.3632	37349	423162	1.86	6.4237	80779	155673	2.86	17.462	24208	057269
0.87	2.3869	37784	418952	1.87	6.4883	81213	154124	2.87	17.637	24643	056699
0.88	2.4109	38218	414783	1.88	6.5535	81647	152590	2.88	17.814	25077	056135
0.89	2.4351	38652	410656	1.89	6.6194	82082	151072	2.89	17.993	25511	055576
0.90	2.4596	0.39087	0.406570	1.90	6.6859	0.82516	0.149569	2.90	18.174	1.25945	0.055023
0.91	2.4843	39521	402524	1.91	6.7531	82950	148080	2.91	18.357	26380	054476
0.92	2.5093	39955	398519	1.92	6.8210	83385	146607	2.92	18.541	26814	053934
0.93	2.5345	40389	394554	1.93	6.8895	83819	145148	2.93	18.728	27248	053397
0.94	2.5600	40824	390628	1.94	6.9588	84253	143704	2.94	18.916	27683	052866
0.95	2.5857	0.41258	0.386741	1.95	7.0287	0.84687	0.142274	2.95	19.106	1.28117	0.052340
0.96	2.6117	41692	382893	1.96	7.0993	85122	140858	2.96	19.298	28551	051819
0.97	2.6379	42127	379083	1.97	7.1707	85556	139457	2.97	19.492	28985	051303
0.98	2.6645	42561	375311	1.98	7.2427	85990	138069	2.98	19.688	29420	050793
0.99	2.6912	42995	371577	1.99	7.3155	86425	136695	2.99	19.886	29854	050287

x	e^x	$\log_{10}(e^x)$	e^{-x}
3.00	20.086	1.30288	0.049787
3.01	20.287	1.30723	049292
3.02	20.491	1.31157	048801
3.03	20.697	1.31591	048316
3.04	20.905	1.32026	047835
3.05	21.115	1.32460	0.047359
3.06	21.328	1.32894	046888
3.07	21.542	1.33328	046421
3.08	21.758	1.33763	045959
3.09	21.977	1.34197	045502
3.10	22.198	1.34631	0.045049
3.11	22.421	1.35066	044601
3.12	22.646	1.35500	044157
3.13	22.874	1.35934	043718
3.14	23.104	1.36368	043283
3.15	23.336	1.36803	0.042852
3.16	23.571	1.37237	042426
3.17	23.807	1.37671	042004
3.18	24.047	1.38106	041586
3.19	24.288	1.38540	041172
3.20	24.533	1.38974	0.040762
3.21	24.779	1.39409	040357
3.22	25.028	1.39843	039955
3.23	25.280	1.40277	039557
3.24	25.534	1.40711	039164
3.25	25.790	1.41146	0.038774
3.26	26.050	1.41580	038388
3.27	26.311	1.42014	038006
3.28	26.576	1.42449	037628
3.29	26.843	1.42883	037254
3.30	27.113	1.43317	0.036883
3.31	27.385	1.43751	036516
3.32	27.660	1.44186	036153
3.33	27.938	1.44620	035793
3.34	28.219	1.45054	035437
3.35	28.503	1.45489	0.035084
3.36	28.789	1.45923	034735
3.37	29.079	1.46357	034390
3.38	29.371	1.46792	034047
3.39	29.666	1.47226	033709
3.40	29.964	1.47660	0.033373
3.41	30.265	1.48094	033041
3.42	30.569	1.48529	032712
3.43	30.877	1.48963	032387
3.44	31.187	1.49397	032065
3.45	31.500	1.49832	0.031746
3.46	31.817	1.50266	031430
3.47	32.137	1.50700	031117
3.48	32.460	1.51134	030807
3.49	32.786	1.51569	030501
3.50	33.115	1.52003	0.030197
3.51	33.448	1.52437	029897
3.52	33.784	1.52872	029599
3.53	34.124	1.53306	029305
3.54	34.467	1.53740	029013
3.55	34.813	1.54175	0.028725
3.56	35.163	1.54609	028439
3.57	35.517	1.55043	028156
3.58	35.874	1.55477	027876
3.59	36.234	1.55912	027598
3.60	36.598	1.56346	0.027324
3.61	36.966	1.56780	027052
3.62	37.338	1.57215	026783
3.63	37.713	1.57649	026516
3.64	38.092	1.58083	026252
3.65	38.475	1.58517	0.025991
3.66	38.861	1.58952	025733
3.67	39.252	1.59386	025476
3.68	39.646	1.59820	025223
3.69	40.045	1.60255	024972
3.70	40.447	1.60689	0.024724
3.71	40.854	1.61123	024478
3.72	41.264	1.61558	024234
3.73	41.679	1.61992	023993
3.74	42.098	1.62426	023754
3.75	42.521	1.62860	0.023518
3.76	42.948	1.63295	023284
3.77	43.380	1.63729	023052
3.78	43.816	1.64163	022823
3.79	44.256	1.64598	022596
3.80	44.701	1.65032	0.022371
3.81	45.150	1.65466	022148
3.82	45.604	1.65900	021928
3.83	46.063	1.66335	021710
3.84	46.525	1.66769	021494
3.85	46.993	1.67203	0.021280
3.86	47.465	1.67638	021068
3.87	47.942	1.68072	020858
3.88	48.424	1.68506	020651
3.89	48.911	1.68941	020445
3.90	49.402	1.69375	0.020242
3.91	49.899	1.69809	020041
3.92	50.400	1.70243	019841
3.93	50.907	1.70678	019644
3.94	51.419	1.71112	019448
3.95	51.935	1.71546	0.019255
3.96	52.457	1.71981	019063
3.97	52.985	1.72415	018873
3.98	53.517	1.72849	018686
3.99	54.055	1.73283	018500

x	e^x	$\log_{10}(e^x)$	e^{-x}
4.00	54.598	1.73718	0.018316
4.01	55.147	1.74152	018133
4.02	55.701	1.74586	017953
4.03	56.261	1.75021	017774
4.04	56.826	1.75455	017597
4.05	57.397	1.75889	0.017422
4.06	57.974	1.76324	017249
4.07	58.557	1.76758	017077
4.08	59.145	1.77192	016907
4.09	59.740	1.77626	016739
4.10	60.340	1.78061	0.016573
4.11	60.947	1.78495	016408
4.12	61.559	1.78929	016245
4.13	62.178	1.79364	016083
4.14	62.803	1.79798	015923
4.15	63.434	1.80232	0.015764
4.16	64.072	1.80667	015608
4.17	64.715	1.81101	015452
4.18	65.366	1.81535	015299
4.19	66.023	1.81969	015146
4.20	66.686	1.82404	0.014996
4.21	67.357	1.82838	014846
4.22	68.033	1.83272	014699
4.23	68.717	1.83707	014552
4.24	69.408	1.84141	014408
4.25	70.105	1.84575	0.014264
4.26	70.810	1.85009	014122
4.27	71.522	1.85444	013982
4.28	72.240	1.85878	013843
4.29	72.966	1.86312	013705
4.30	73.700	1.86747	0.013569
4.31	74.440	1.87181	013434
4.32	75.189	1.87615	013300
4.33	75.944	1.88050	013168
4.34	76.708	1.88484	013037
4.35	77.478	1.88918	0.012907
4.36	78.257	1.89352	012778
4.37	79.044	1.89787	012651
4.38	79.838	1.90221	012525
4.39	80.640	1.90655	012401
4.40	81.451	1.91090	0.012277
4.41	82.269	1.91524	012155
4.42	83.096	1.91958	012034
4.43	83.931	1.92392	011914
4.44	84.775	1.92827	011796
4.45	85.627	1.93261	0.011679
4.46	86.488	1.93695	011562
4.47	87.357	1.94130	011447
4.48	88.235	1.94564	011333
4.49	89.121	1.94998	011221
4.50	90.017	1.95433	0.011109
4.51	90.922	1.95867	010998
4.52	91.836	1.96301	010889
4.53	92.759	1.96735	010781
4.54	93.691	1.97170	010673
4.55	94.632	1.97604	0.010567
4.56	95.583	1.98038	010462
4.57	96.544	1.98473	010358
4.58	97.514	1.98907	010255
4.59	98.494	1.99341	010153
4.60	99.484	1.99775	0.010052
4.61	100.48	2.00210	009952
4.62	101.49	2.00644	009853
4.63	102.51	2.01078	009755
4.64	103.54	2.01513	009658
4.65	104.58	2.01947	0.009562
4.66	105.64	2.02381	009466
4.67	106.70	2.02816	009372
4.68	107.77	2.03250	009279
4.69	108.85	2.03684	009187
4.70	109.95	2.04118	0.009095
4.71	111.05	2.04553	009005
4.72	112.17	2.04987	008915
4.73	113.30	2.05421	008826
4.74	114.43	2.05856	008739
4.75	115.58	2.06290	0.008652
4.76	116.75	2.06724	008566
4.77	117.92	2.07158	008480
4.78	119.10	2.07593	008396
4.79	120.30	2.08027	008312
4.80	121.51	2.08461	0.008230
4.81	122.73	2.08896	008148
4.82	123.97	2.09330	008067
4.83	125.21	2.09764	007987
4.84	126.47	2.10199	007907
4.85	127.74	2.10633	0.007828
4.86	129.02	2.11067	007750
4.87	130.32	2.11501	007673
4.88	131.63	2.11936	007597
4.89	132.95	2.12370	007521
4.90	134.29	2.12804	0.007447
4.91	135.64	2.13239	007372
4.92	137.00	2.13673	007299
4.93	138.38	2.14107	007227
4.94	139.77	2.14541	007155
4.95	141.17	2.14976	0.007083
4.96	142.59	2.15410	007013
4.97	144.03	2.15844	006943
4.98	145.47	2.16279	006874
4.99	146.94	2.16713	006806

x	e^x	$\log_{10}(e^x)$	e^{-x}
5.00	148.41	2.17147	0.006738
5.01	149.90	2.17582	006671
5.02	151.41	2.18016	006605
5.03	152.93	2.18450	006539
5.04	154.47	2.18884	006474
5.05	156.02	2.19319	0.006409
5.06	157.59	2.19753	006346
5.07	159.17	2.20187	006282
5.08	160.77	2.20622	006220
5.09	162.39	2.21056	006158
5.10	164.02	2.21490	0.006097
5.11	165.67	2.21924	006036
5.12	167.34	2.22359	005976
5.13	169.02	2.22793	005917
5.14	170.72	2.23227	005858
5.15	172.43	2.23662	0.005799
5.16	174.16	2.24096	005742
5.17	175.91	2.24530	005685
5.18	177.68	2.24965	005628
5.19	179.47	2.25399	005572
5.20	181.27	2.25833	0.005517
5.21	183.09	2.26267	005462
5.22	184.93	2.26702	005407
5.23	186.79	2.27136	005354
5.24	188.67	2.27570	005300
5.25	190.57	2.28005	0.005248
5.26	192.48	2.28439	005195
5.27	194.42	2.28873	005144
5.28	196.37	2.29307	005092
5.29	198.34	2.29742	005042
5.30	200.34	2.30176	0.004992
5.31	202.35	2.30610	004942
5.32	204.38	2.31045	004893
5.33	206.44	2.31479	004844
5.34	208.51	2.31913	004796
5.35	210.61	2.32348	0.004748
5.36	212.72	2.32782	004701
5.37	214.86	2.33216	004654
5.38	217.02	2.33650	004608
5.39	219.20	2.34085	004562
5.40	221.41	2.34519	0.004517
5.41	223.63	2.34953	004472
5.42	225.88	2.35388	004427
5.43	228.15	2.35822	004383
5.44	230.44	2.36256	004339
5.45	232.76	2.36690	0.004296
5.46	235.10	2.37125	004254
5.47	237.46	2.37559	004211
5.48	239.85	2.37993	004169
5.49	242.26	2.38428	004128
5.5	244.69	2.38862	0.004087
5.6	270.43	2.43205	003698
5.7	298.87	2.47548	003346
5.8	330.30	2.51891	003028
5.9	365.04	2.56234	002739
6.0	403.43	2.60577	0.002479
6.1	445.86	2.64920	002243
6.2	492.75	2.69263	002029
6.3	544.57	2.73606	001836
6.4	601.85	2.77948	001662
6.5	665.14	2.82291	0.001503
6.6	735.10	2.86634	001360
6.7	812.41	2.90977	001231
6.8	897.85	2.95320	001114
6.9	992.27	2.99663	001008
7.0	1096.6	3.04006	0.000912
7.1	1212.0	3.08349	000825
7.2	1339.4	3.12692	000747
7.3	1480.3	3.17035	000676
7.4	1636.0	3.21378	000611
7.5	1808.0	3.25721	0.000553
7.6	1998.2	3.30064	000501
7.7	2208.3	3.34407	000453
7.8	2440.6	3.38750	000410
7.9	2697.3	3.43093	000371
8.0	2981.0	3.47436	0.000336
8.1	3294.5	3.51779	000304
8.2	3641.0	3.56121	000275
8.3	4023.9	3.60464	000249
8.4	4447.1	3.64807	000225
8.5	4914.8	3.69150	0.000204
8.6	5431.7	3.73493	000184
8.7	6002.9	3.77836	000167
8.8	6634.2	3.82179	000151
8.9	7332.0	3.86522	000136
9.0	8103.1	3.90865	0.000123
9.1	8955.3	3.95208	000112
9.2	9897.1	3.99551	000101
9.3	10938	4.03894	000091
9.4	12088	4.08237	000083
9.5	13360	4.12580	0.000075
9.6	14765	4.16923	000068
9.7	16318	4.21266	000061
9.8	18034	4.25609	000056
9.9	19930	4.29952	000050
10.0	22026	4.34294	0.000045

Reciprocals[1] of the Integers 1–999

Reciprocal of $n = 1/n$

n	0	1	2	3	4	5	6	7	8	9
0		1.0 000 0000	0.5 000 0000	0.3 333 3333	0.2 500 0000	0.2 000 0000	0.1 666 6667	0.1 428 5714	0.1 250 0000	0.1 111 1111
10	0.1 000 0000	0.0 909 0909	0.0 833 3333	0.0 769 2308	0.0 714 2857	0.0 666 6667	0.0 625 0000	0.0 588 2353	0.0 555 5556	0.0 526 3158
20	0.0 500 0000	476 1905	454 5455	434 7826	416 6667	400 0000	384 6154	370 3704	357 1429	344 8276
30	333 3333	322 5806	312 5000	303 0303	294 1176	285 7143	277 7778	270 2703	263 1579	256 4103
40	250 0000	243 9024	238 0952	232 5581	227 2727	222 2222	217 3913	212 7660	208 3333	204 0816
50	0.0 200 0000	0.0 196 0784	0.0 192 3077	0.0 188 6792	0.0 185 1852	0.0 181 8182	0.0 178 5714	0.0 175 4386	0.0 172 4138	0.0 169 4915
60	166 6667	163 9344	161 2903	158 7302	156 2500	153 8462	151 5152	149 2537	147 0588	144 9275
70	142 8571	140 8451	138 8889	136 9863	135 1351	133 3333	131 5789	129 8701	128 2051	126 5823
80	125 0000	123 4568	121 9512	120 4819	119 0476	117 6471	116 2791	114 9425	113 6364	112 3596
90	111 1111	109 8901	108 6957	107 5269	106 3830	105 2632	104 1667	103 0928	102 0408	101 0101
100	0.0 100 0000	0.00 990 0990	0.00 980 3922	0.00 970 8738	0.00 961 5385	0.00 952 3810	0.00 943 3962	0.00 934 5794	0.00 925 9259	0.00 917 4312
110	0.00 909 0909	900 9009	892 8571	884 9558	877 1930	869 5652	862 0690	854 7009	847 4576	840 3361
120	833 3333	826 4463	819 6721	813 0081	806 4516	800 0000	793 6508	787 4016	781 2500	775 1938
130	769 2308	763 3588	757 5758	751 8797	746 2687	740 7407	735 2941	729 9270	724 6377	719 4245
140	714 2857	709 2199	704 2254	699 3007	694 4444	689 6552	684 9315	680 2721	675 6757	671 1409
150	0.00 666 6667	0.00 662 2517	0.00 657 8947	0.00 653 5948	0.00 649 3506	0.00 645 1613	0.00 641 0256	0.00 636 9427	0.00 632 9114	0.00 628 9308
160	625 0000	621 1180	617 2840	613 4969	609 7561	606 0606	602 4096	598 8024	595 2381	591 7160
170	588 2353	584 7953	581 3953	578 0347	574 7126	571 4286	568 1818	564 9718	561 7978	558 6592
180	555 5556	552 4862	549 4505	546 4481	543 4783	540 5405	537 6344	534 7594	531 9149	529 1005
190	526 3158	523 5602	520 8333	518 1347	515 4639	512 8205	510 2041	507 6142	505 0505	502 5126
200	0.00 500 0000	0.00 497 5124	0.00 495 0495	0.00 492 6108	0.00 490 1961	0.00 487 8049	0.00 485 4369	0.00 483 0918	0.00 480 7692	0.00 478 4689
210	476 1905	473 9336	471 6981	469 4836	467 2897	465 1163	462 9630	460 8295	458 7156	456 6210
220	454 5455	452 4887	450 4505	448 4305	446 4286	444 4444	442 4779	440 5286	438 5965	436 6812
230	434 7826	432 9004	431 0345	429 1845	427 3504	425 5319	423 7288	421 9409	420 1681	418 4100
240	416 6667	414 9378	413 2231	411 5226	409 8361	408 1633	406 5041	404 8583	403 2258	401 6064
250	0.00 400 0000	0.00 398 4064	0.00 396 8254	0.00 395 2569	0.00 393 7008	0.00 392 1569	0.00 390 6250	0.00 389 1051	0.00 387 5969	0.00 386 1004
260	384 6154	383 1418	381 6794	380 2281	378 7879	377 3585	375 9398	374 5318	373 1343	371 7472
270	370 3704	369 0037	367 6471	366 3004	364 9635	363 6364	362 3188	361 0108	359 7122	358 4229
280	357 1429	355 8719	354 6099	353 3569	352 1127	350 8772	349 6503	348 4321	347 2222	346 0208
290	344 8276	343 6426	342 4658	341 2969	340 1361	338 9831	337 8378	336 7003	335 5705	334 4482
300	0.00 333 3333	0.00 332 2259	0.00 331 1258	0.00 330 0330	0.00 328 9474	0.00 327 8689	0.00 326 7974	0.00 325 7329	0.00 324 6753	0.00 323 6246
310	322 5806	321 5434	320 5128	319 4888	318 4713	317 4603	316 4557	315 4574	314 4654	313 4796
320	312 5000	311 5265	310 5590	309 5975	308 6420	307 6923	306 7485	305 8104	304 8780	303 9514
330	303 0303	302 1148	301 2048	300 3003	299 4012	298 5075	297 6190	296 7359	295 8580	294 9853
340	294 1176	293 2551	292 3977	291 5452	290 6977	289 8551	289 0173	288 1844	287 3563	286 5330
350	0.00 285 7143	0.00 284 9003	0.00 284 0909	0.00 283 2861	0.00 282 4859	0.00 281 6901	0.00 280 8989	0.00 280 1120	0.00 279 3296	0.00 278 5515
360	277 7778	277 0083	276 2431	275 4821	274 7253	273 9726	273 2240	272 4796	271 7391	271 0027
370	270 2703	269 5418	268 8172	268 0965	267 3797	266 6667	265 9574	265 2520	264 5503	263 8522
380	263 1579	262 4672	261 7801	261 0966	260 4167	259 7403	259 0674	258 3979	257 7320	257 0694
390	256 4103	255 7545	255 1020	254 4529	253 8071	253 1646	252 5253	251 8892	251 2563	250 6266
400	0.00 250 0000	0.00 249 3766	0.00 248 7562	0.00 248 1390	0.00 247 5248	0.00 246 9136	0.00 246 3054	0.00 245 7002	0.00 245 0980	0.00 244 4988
410	243 9024	243 3090	242 7184	242 1308	241 5459	240 9639	240 3846	239 8082	239 2344	238 6635
420	238 0952	237 5297	236 9668	236 4066	235 8491	235 2941	234 7418	234 1920	233 6449	233 1002
430	232 5581	232 0186	231 4815	230 9469	230 4147	229 8851	229 3578	228 8330	228 3105	227 7904
440	227 2727	226 7574	226 2443	225 7336	225 2252	224 7191	224 2152	223 7136	223 2143	222 7171
450	0.00 222 2222	0.00 221 7295	0.00 221 2389	0.00 220 7506	0.00 220 2643	0.00 219 7802	0.00 219 2982	0.00 218 8184	0.00 218 3406	0.00 217 8649
460	217 3913	216 9197	216 4502	215 9827	215 5172	215 0538	214 5923	214 1328	213 6752	213 2196
470	212 7660	212 3142	211 8644	211 4165	210 9705	210 5263	210 0840	209 6436	209 2050	208 7683
480	208 3333	207 9002	207 4689	207 0393	206 6116	206 1856	205 7613	205 3388	204 9180	204 4990
490	204 0816	203 6660	203 2520	202 8398	202 4291	202 0202	201 6129	201 2072	200 8032	200 4008
500	0.00 200 0000	0.00 199 6008	0.00 199 2032	0.00 198 8072	0.00 198 4127	0.00 198 0198	0.00 197 6285	0.00 197 2387	0.00 196 8504	0.00 196 4637
510	196 0784	195 6947	195 3125	194 9318	194 5525	194 1748	193 7984	193 4236	193 0502	192 6782
520	192 3077	191 9386	191 5709	191 2046	190 8397	190 4762	190 1141	189 7533	189 3939	189 0359
530	188 6792	188 3239	187 9699	187 6173	187 2659	186 9159	186 5672	186 2197	185 8736	185 5288
540	185 1852	184 8429	184 5018	184 1621	183 8235	183 4862	183 1502	182 8154	182 4818	182 1494
550	0.00 181 8182	0.00 181 4882	0.00 181 1594	0.00 180 8318	0.00 180 5054	0.00 180 1802	0.00 179 8561	0.00 179 5332	0.00 179 2115	0.00 178 8909
560	178 5714	178 2531	177 9359	177 6199	177 3050	176 9912	176 6784	176 3668	176 0563	175 7469
570	175 4386	175 1313	174 8252	174 5201	174 2160	173 9130	173 6111	173 3102	173 0104	172 7116
580	172 4138	172 1170	171 8213	171 5266	171 2329	170 9402	170 6485	170 3578	170 0680	169 7793
590	169 4915	169 2047	168 9189	168 6341	168 3502	168 0672	167 7852	167 5042	167 2241	166 9449
600	0.00 166 6667	0.00 166 3894	0.00 166 1130	0.00 165 8375	0.00 165 5629	0.00 165 2893	0.00 165 0165	0.00 164 7446	0.00 164 4737	0.00 164 2036
610	163 9344	163 6661	163 3987	163 1321	162 8664	162 6016	162 3377	162 0746	161 8123	161 5509
620	161 2903	161 0306	160 7717	160 5136	160 2564	160 0000	159 7444	159 4896	159 2357	158 9825
630	158 7302	158 4786	158 2278	157 9779	157 7287	157 4803	157 2327	156 9859	156 7398	156 4945
640	156 2500	156 0062	155 7632	155 5210	155 2795	155 0388	154 7988	154 5595	154 3210	154 0832
650	0.00 153 8462	0.00 153 6098	0.00 153 3742	0.00 153 1394	0.00 152 9052	0.00 152 6718	0.00 152 4390	0.00 152 2070	0.00 151 9757	0.00 151 7451
660	151 5152	151 2859	151 0574	150 8296	150 6024	150 3759	150 1502	149 9250	149 7006	149 4768
670	149 2537	149 0313	148 8095	148 5884	148 3680	148 1481	147 9290	147 7105	147 4926	147 2754
680	147 0588	146 8429	146 6276	146 4129	146 1988	145 9854	145 7726	145 5604	145 3488	145 1379
690	144 9275	144 7178	144 5087	144 3001	144 0922	143 8849	143 6782	143 4720	143 2665	143 0615
700	0.00 142 8571	0.00 142 6534	0.00 142 4501	0.00 142 2475	0.00 142 0455	0.00 141 8440	0.00 141 6431	0.00 141 4427	0.00 141 2429	0.00 141 0437
710	140 8451	140 6470	140 4494	140 2525	140 0560	139 8601	139 6648	139 4700	139 2758	139 0821
720	138 8889	138 6963	138 5042	138 3126	138 1215	137 9310	137 7410	137 5516	137 3626	137 1742
730	136 9863	136 7989	136 6120	136 4256	136 2398	136 0544	135 8696	135 6852	135 5014	135 3180
740	135 1351	134 9528	134 7709	134 5895	134 4086	134 2282	134 0483	133 8688	133 6898	133 5113
750	0.00 133 3333	0.00 133 1558	0.00 132 9787	0.00 132 8021	0.00 132 6260	0.00 132 4503	0.00 132 2751	0.00 132 1004	0.00 131 9261	0.00 131 7523
760	131 5789	131 4060	131 2336	131 0616	130 8901	130 7190	130 5483	130 3781	130 2083	130 0390
770	129 8701	129 7017	129 5337	129 3661	129 1990	129 0323	128 8660	128 7001	128 5347	128 3697
780	128 2051	128 0410	127 8772	127 7139	127 5510	127 3885	127 2265	127 0648	126 9036	126 7427
790	126 5823	126 4223	126 2626	126 1034	125 9446	125 7862	125 6281	125 4705	125 3133	125 1564
800	0.00 125 0000	0.00 124 8439	0.00 124 6883	0.00 124 5330	0.00 124 3781	0.00 124 2236	0.00 124 0695	0.00 123 9157	0.00 123 7624	0.00 123 6094
810	123 4568	123 3046	123 1527	123 0012	122 8501	122 6994	122 5490	122 3990	122 2494	122 1001
820	121 9512	121 8027	121 6545	121 5067	121 3592	121 2121	121 0654	120 9190	120 7729	120 6273
830	120 4819	120 3369	120 1923	120 0480	119 9041	119 7605	119 6172	119 4743	119 3317	119 1895
840	119 0476	118 9061	118 7648	118 6240	118 4834	118 3432	118 2033	118 0638	117 9245	117 7856
850	0.00 117 6471	0.00 117 5088	0.00 117 3709	0.00 117 2333	0.00 117 0960	0.00 116 9591	0.00 116 8224	0.00 116 6861	0.00 116 5501	0.00 116 4144
860	116 2791	116 1440	116 0093	115 8749	115 7407	115 6069	115 4734	115 3403	115 2074	115 0748
870	114 9425	114 8106	114 6789	114 5475	114 4165	114 2857	114 1553	114 0251	113 8952	113 7656
880	113 6364	113 5074	113 3787	113 2503	113 1222	112 9944	112 8668	112 7396	112 6126	112 4859
890	112 3596	112 2334	112 1076	111 9821	111 8568	111 7318	111 6071	111 4827	111 3586	111 2347
900	0.00 111 1111	0.00 110 9878	0.00 110 8647	0.00 110 7420	0.00 110 6195	0.00 110 4972	0.00 110 3753	0.00 110 2536	0.00 110 1322	0.00 110 0110
910	109 8901	109 7695	109 6491	109 5290	109 4092	109 2896	109 1703	109 0513	108 9325	108 8139
920	108 6957	108 5776	108 4599	108 3424	108 2251	108 1081	107 9914	107 8749	107 7586	107 6426
930	107 5269	107 4114	107 2961	107 1811	107 0664	106 9519	106 8376	106 7236	106 6098	106 4963
940	106 3830	106 2699	106 1571	106 0445	105 9322	105 8201	105 7082	105 5966	105 4852	105 3741
950	0.00 105 2632	0.00 105 1525	0.00 105 0420	0.00 104 9318	0.00 104 8218	0.00 104 7120	0.00 104 6025	0.00 104 4932	0.00 104 3841	0.00 104 2753
960	104 1667	104 0583	103 9501	103 8422	103 7344	103 6269	103 5197	103 4126	103 3058	103 1992
970	103 0928	102 9866	102 8807	102 7749	102 6694	102 5641	102 4590	102 3541	102 2495	102 1450
980	102 0408	101 9368	101 8330	101 7294	101 6260	101 5228	101 4199	101 3171	101 2146	101 1122
990	101 0101	100 9082	100 8065	100 7049	100 6036	100 5025	100 4016	100 3009	100 2004	100 1001

[1] Values from COMRIE, L. J. (Ed.), *Barlow's Tables of Squares, Cubes, Square Roots, Cube Roots and Reciprocals of All Integers up to 12,500*, 4th ed., Spon, London, 1958. Reprinted by kind permission of the editor and publishers.

n	0	1	2	3	4	5	6	7	8	9
0	0	1	8	27	64	125	216	343	512	729
10	1 000	1 331	1 728	2 197	2 744	3 375	4 096	4 913	5 832	6 859
20	8 000	9 261	10 648	12 167	13 824	15 625	17 576	19 683	21 952	24 389
30	27 000	29 791	32 768	35 937	39 304	42 875	46 656	50 653	54 872	59 319
40	64 000	68 921	74 088	79 507	85 184	91 125	97 336	103 823	110 592	117 649
50	125 000	132 651	140 608	148 877	157 464	166 375	175 616	185 193	195 112	205 379
60	216 000	226 981	238 328	250 047	262 144	274 625	287 496	300 763	314 432	328 509
70	343 000	357 911	373 248	389 017	405 224	421 875	438 976	456 533	474 552	493 039
80	512 000	531 441	551 368	571 787	592 704	614 125	636 056	658 503	681 472	704 969
90	729 000	753 571	778 688	804 357	830 584	857 375	884 736	912 673	941 192	970 299
100	1 000 000	1 030 301	1 061 208	1 092 727	1 124 864	1 157 625	1 191 016	1 225 043	1 259 712	1 295 029
110	1 331 000	1 367 631	1 404 928	1 442 897	1 481 544	1 520 875	1 560 896	1 601 613	1 643 032	1 685 159
120	1 728 000	1 771 561	1 815 848	1 860 867	1 906 624	1 953 125	2 000 376	2 048 383	2 097 152	2 146 689
130	2 197 000	2 248 091	2 299 968	2 352 637	2 406 104	2 460 375	2 515 456	2 571 353	2 628 072	2 685 619
140	2 744 000	2 803 221	2 863 288	2 924 207	2 985 984	3 048 625	3 112 136	3 176 523	3 241 792	3 307 949
150	3 375 000	3 442 951	3 511 808	3 581 577	3 652 264	3 723 875	3 796 416	3 869 893	3 944 312	4 019 679
160	4 096 000	4 173 281	4 251 528	4 330 747	4 410 944	4 492 125	4 574 296	4 657 463	4 741 632	4 826 809
170	4 913 000	5 000 211	5 088 448	5 177 717	5 268 024	5 359 375	5 451 776	5 545 233	5 639 752	5 735 339
180	5 832 000	5 929 741	6 028 568	6 128 487	6 229 504	6 331 625	6 434 856	6 539 203	6 644 672	6 751 269
190	6 859 000	6 967 871	7 077 888	7 189 057	7 301 384	7 414 875	7 529 536	7 645 373	7 762 392	7 880 599
200	8 000 000	8 120 601	8 242 408	8 365 427	8 489 664	8 615 125	8 741 816	8 869 743	8 998 912	9 129 329
210	9 261 000	9 393 931	9 528 128	9 663 597	9 800 344	9 938 375	10 077 696	10 218 313	10 360 232	10 503 459
220	10 648 000	10 793 861	10 941 048	11 089 567	11 239 424	11 390 625	11 543 176	11 697 083	11 852 352	12 008 989
230	12 167 000	12 326 391	12 487 168	12 649 337	12 812 904	12 977 875	13 144 256	13 312 053	13 481 272	13 651 919
240	13 824 000	13 997 521	14 172 488	14 348 907	14 526 784	14 706 125	14 886 936	15 069 223	15 252 992	15 438 249
250	15 625 000	15 813 251	16 003 008	16 194 277	16 387 064	16 581 375	16 777 216	16 974 593	17 173 512	17 373 979
260	17 576 000	17 779 581	17 984 728	18 191 447	18 399 744	18 609 625	18 821 096	19 034 163	19 248 832	19 465 109
270	19 683 000	19 902 511	20 123 648	20 346 417	20 570 824	20 796 875	21 024 576	21 253 933	21 484 952	21 717 639
280	21 952 000	22 188 041	22 425 768	22 665 187	22 906 304	23 149 125	23 393 656	23 639 903	23 887 872	24 137 569
290	24 389 000	24 642 171	24 897 088	25 153 757	25 412 184	25 672 375	25 934 336	26 198 073	26 463 592	26 730 899
300	27 000 000	27 270 901	27 543 608	27 818 127	28 094 464	28 372 625	28 652 616	28 934 443	29 218 112	29 503 629
310	29 791 000	30 080 231	30 371 328	30 664 297	30 959 144	31 255 875	31 554 496	31 855 013	32 157 432	32 461 759
320	32 768 000	33 076 161	33 386 248	33 698 267	34 012 224	34 328 125	34 645 976	34 965 783	35 287 552	35 611 289
330	35 937 000	36 264 691	36 594 368	36 926 037	37 259 704	37 595 375	37 933 056	38 272 753	38 614 472	38 958 219
340	39 304 000	39 651 821	40 001 688	40 353 607	40 707 584	41 063 625	41 421 736	41 781 923	42 144 192	42 508 549
350	42 875 000	43 243 551	43 614 208	43 986 977	44 361 864	44 738 875	45 118 016	45 499 293	45 882 712	46 268 279
360	46 656 000	47 045 881	47 437 928	47 832 147	48 228 544	48 627 125	49 027 896	49 430 863	49 836 032	50 243 409
370	50 653 000	51 064 811	51 478 848	51 895 117	52 313 624	52 734 375	53 157 376	53 582 633	54 010 152	54 439 939
380	54 872 000	55 306 341	55 742 968	56 181 887	56 623 104	57 066 625	57 512 456	57 960 603	58 411 072	58 863 869
390	59 319 000	59 776 471	60 236 288	60 698 457	61 162 984	61 629 875	62 099 136	62 570 773	63 044 792	63 521 199
400	64 000 000	64 481 201	64 964 808	65 450 827	65 939 264	66 430 125	66 923 416	67 419 143	67 917 312	68 417 929
410	68 921 000	69 426 531	69 934 528	70 444 997	70 957 944	71 473 375	71 991 296	72 511 713	73 034 632	73 560 059
420	74 088 000	74 618 461	75 151 448	75 686 967	76 225 024	76 765 625	77 308 776	77 854 483	78 402 752	78 953 589
430	79 507 000	80 062 991	80 621 568	81 182 737	81 746 504	82 312 875	82 881 856	83 453 453	84 027 672	84 604 519
440	85 184 000	85 766 121	86 350 888	86 938 307	87 528 384	88 121 125	88 716 536	89 314 623	89 915 392	90 518 849
450	91 125 000	91 733 851	92 345 408	92 959 677	93 576 664	94 196 375	94 818 816	95 443 993	96 071 912	96 702 579
460	97 336 000	97 972 181	98 611 128	99 252 847	99 897 344	100 544 625	101 194 696	101 847 563	102 503 232	103 161 709
470	103 823 000	104 487 111	105 154 048	105 823 817	106 496 424	107 171 875	107 850 176	108 531 333	109 215 352	109 902 239
480	110 592 000	111 284 641	111 980 168	112 678 587	113 379 904	114 084 125	114 791 256	115 501 303	116 214 272	116 930 169
490	117 649 000	118 370 771	119 095 488	119 823 157	120 553 784	121 287 375	122 023 936	122 763 473	123 505 992	124 251 499
500	125 000 000	125 751 501	126 506 008	127 263 527	128 024 064	128 787 625	129 554 216	130 323 843	131 096 512	131 872 229
510	132 651 000	133 432 831	134 217 728	135 005 697	135 796 744	136 590 875	137 388 096	138 188 413	138 991 832	139 798 359
520	140 608 000	141 420 761	142 236 648	143 055 667	143 877 824	144 703 125	145 531 576	146 363 183	147 197 952	148 035 889
530	148 877 000	149 721 291	150 568 768	151 419 437	152 273 304	153 130 375	153 990 656	154 854 153	155 720 872	156 590 819
540	157 464 000	158 340 421	159 220 088	160 103 007	160 989 184	161 878 625	162 771 336	163 667 323	164 566 592	165 469 149
550	166 375 000	167 284 151	168 196 608	169 112 377	170 031 464	170 953 875	171 879 616	172 808 693	173 741 112	174 676 879
560	175 616 000	176 558 481	177 504 328	178 453 547	179 406 144	180 362 125	181 321 496	182 284 263	183 250 432	184 220 009
570	185 193 000	186 169 411	187 149 248	188 132 517	189 119 224	190 109 375	191 102 976	192 100 033	193 100 552	194 104 539
580	195 112 000	196 122 941	197 137 368	198 155 287	199 176 704	200 201 625	201 230 056	202 262 003	203 297 472	204 336 469
590	205 379 000	206 425 071	207 474 688	208 527 857	209 584 584	210 644 875	211 708 736	212 776 173	213 847 192	214 921 799
600	216 000 000	217 081 801	218 167 208	219 256 227	220 348 864	221 445 125	222 545 016	223 648 543	224 755 712	225 866 529
610	226 981 000	228 099 131	229 220 928	230 346 397	231 475 544	232 608 375	233 744 896	234 885 113	236 029 032	237 176 659
620	238 328 000	239 483 061	240 641 848	241 804 367	242 970 624	244 140 625	245 314 376	246 491 883	247 673 152	248 858 189
630	250 047 000	251 239 591	252 435 968	253 636 137	254 840 104	256 047 875	257 259 456	258 474 853	259 694 072	260 917 119
640	262 144 000	263 374 721	264 609 288	265 847 707	267 089 984	268 336 125	269 586 136	270 840 023	272 097 792	273 359 449
650	274 625 000	275 894 451	277 167 808	278 445 077	279 726 264	281 011 375	282 300 416	283 593 393	284 890 312	286 191 179
660	287 496 000	288 804 781	290 117 528	291 434 247	292 754 944	294 079 625	295 408 296	296 740 963	298 077 632	299 418 309
670	300 763 000	302 111 711	303 464 448	304 821 217	306 182 024	307 546 875	308 915 776	310 288 733	311 665 752	313 046 839
680	314 432 000	315 821 241	317 214 568	318 611 987	320 013 504	321 419 125	322 828 856	324 242 703	325 660 672	327 082 769
690	328 509 000	329 939 371	331 373 888	332 812 557	334 255 384	335 702 375	337 153 536	338 608 873	340 068 392	341 532 099
700	343 000 000	344 472 101	345 948 408	347 428 927	348 913 664	350 402 625	351 895 816	353 393 243	354 894 912	356 400 829
710	357 911 000	359 425 431	360 944 128	362 467 097	363 994 344	365 525 875	367 061 696	368 601 813	370 146 232	371 694 959
720	373 248 000	374 805 361	376 367 048	377 933 067	379 503 424	381 078 125	382 657 176	384 240 583	385 828 352	387 420 489
730	389 017 000	390 617 891	392 223 168	393 832 837	395 446 904	397 065 375	398 688 256	400 315 553	401 947 272	403 583 419
740	405 224 000	406 869 021	408 518 488	410 172 407	411 830 784	413 493 625	415 160 936	416 832 723	418 508 992	420 189 749
750	421 875 000	423 564 751	425 259 008	426 957 777	428 661 064	430 368 875	432 081 216	433 798 093	435 519 512	437 245 479
760	438 976 000	440 711 081	442 450 728	444 194 947	445 943 744	447 697 125	449 455 096	451 217 663	452 984 832	454 756 609
770	456 533 000	458 314 011	460 099 648	461 889 917	463 684 824	465 484 375	467 288 576	469 097 433	470 910 952	472 729 139
780	474 552 000	476 379 541	478 211 768	480 048 687	481 890 304	483 736 625	485 587 656	487 443 403	489 303 872	491 169 069
790	493 039 000	494 913 671	496 793 088	498 677 257	500 566 184	502 459 875	504 358 336	506 261 573	508 169 592	510 082 399
800	512 000 000	513 922 401	515 849 608	517 781 627	519 718 464	521 660 125	523 606 616	525 557 943	527 514 112	529 475 129
810	531 441 000	533 411 731	535 387 328	537 367 797	539 353 144	541 343 375	543 338 496	545 338 513	547 343 432	549 353 259
820	551 368 000	553 387 661	555 412 248	557 441 767	559 476 224	561 515 625	563 559 976	565 609 283	567 663 552	569 722 789
830	571 787 000	573 856 191	575 930 368	578 009 537	580 093 704	582 182 875	584 277 056	586 376 253	588 480 472	590 589 719
840	592 704 000	594 823 321	596 947 688	599 077 107	601 211 584	603 351 125	605 495 736	607 645 423	609 800 192	611 960 049
850	614 125 000	616 295 051	618 470 208	620 650 477	622 835 864	625 026 375	627 222 016	629 422 793	631 628 712	633 839 779
860	636 056 000	638 277 381	640 503 928	642 735 647	644 972 544	647 214 625	649 461 896	651 714 363	653 972 032	656 234 909
870	658 503 000	660 776 311	663 054 848	665 338 617	667 627 624	669 921 875	672 221 376	674 526 133	676 836 152	679 151 439
880	681 472 000	683 797 841	686 128 968	688 465 387	690 807 104	693 154 125	695 506 456	697 864 103	700 227 072	702 595 369
890	704 969 000	707 347 971	709 732 288	712 121 957	714 516 984	716 917 375	719 323 136	721 734 273	724 150 792	726 572 699
900	729 000 000	731 432 701	733 870 808	736 314 327	738 763 264	741 217 625	743 677 416	746 142 643	748 613 312	751 089 429
910	753 571 000	756 058 031	758 550 528	761 048 497	763 551 944	766 060 875	768 575 296	771 095 213	773 620 632	776 151 559
920	778 688 000	781 229 961	783 777 448	786 330 467	788 889 024	791 453 125	794 022 776	796 597 983	799 178 752	801 765 089
930	804 357 000	806 954 491	809 557 568	812 166 237	814 780 504	817 400 375	820 025 856	822 656 953	825 293 672	827 936 019
940	830 584 000	833 237 621	835 896 888	838 561 807	841 232 384	843 908 625	846 590 536	849 278 123	851 971 392	854 670 349
950	857 375 000	860 085 351	862 801 408	865 523 177	868 250 664	870 983 875	873 722 816	876 467 493	879 217 912	881 974 079
960	884 736 000	887 503 681	890 277 128	893 056 347	895 841 344	898 632 125	901 428 696	904 231 063	907 039 232	909 853 209
970	912 673 000	915 498 611	918 330 048	921 167 317	924 010 424	926 859 375	929 714 176	932 574 833	935 441 352	938 313 739
980	941 192 000	944 076 141	946 966 168	949 862 087	952 763 904	955 671 625	958 585 256	961 504 803	964 430 272	967 361 669
990	970 299 000	973 242 271	976 191 488	979 146 657	982 107 784	985 074 875	988 047 936	991 026 973	994 011 992	997 002 999

† Values from COMRIE, L. J. (Ed.), *Barlow's Tables of Squares, Cubes, Square Roots, Cube Roots and Reciprocals of All Integers up to 12,500*, 4th ed., Spon, London, 1958. Reprinted by kind permission of the editor and publishers

I. Symbols

$a \rightarrow b$	a tending toward b
›	Infinity
m	Limiting value
$\sim b$	a approximately equal to b
$\approx b$	a very nearly equal to b
$= b$	a equal to b [cf. (1) below]
$\equiv b$	a identical with b (for formulae only)
$> b$	a greater than b } Cf. (2) and (3) below
$< b$	a smaller than b } Cf. (2) and (3) below
$\gg b$	a much greater than b
$\ll b$	a much smaller than b
$\neq b$, $\lessgtr b$	a not equal to b
$< a < c$	a greater than b and smaller than c
$\geqq b$, $\geq b$	a equal to or greater than b, i.e., a at least as great as b
$\leqq b$, $\leq b$	a equal to or smaller than b, i.e., a at most as great as b
$\leqq a \leqq c$	a lying between b and c
$a\|$	Absolute value of a; this is always positive, for example $\|-5\| = 5$
-	Addition sign, plus, positive
-	Subtraction sign, minus, negative
: or ·	Multiplication sign, times (the period sign is not used in these *Tables*)
or ÷	Division sign, divided by (the sign ÷ is not used in these *Tables*)
$+ b = c$	$a + b$, read as 'a plus b', denotes the sum of a and b. The result of the addition, c, is also known as the sum
$\sum x_i$	Sum of all values $x_1, x_2, x_3, \ldots$, i.e., of all values x_i, from $i = 1$ to $i = k$ inclusive, or $\sum_1^k x_i = x_1 + x_2 + x_3 + \cdots + x_k$ (the limits of the summation above and below the sign Σ are usually omitted if there is no possibility of confusion)
	Indefinite integral
	Definite integral, or integral between $x = a$ and $x = b$
$- b = c$	$a - b$, read as 'a minus b', denotes subtraction of b from a. a is the minuend, b the subtrahend; $a - b$, or c, is the difference. Subtraction is the opposite of addition
$\times b = c$, $b = c$, $\cdot b = c$	$a \times b$, read as 'a times b', denotes multiplication of a by b. a and b are the multiplicands or factors; $a \times b$, or c, is the product. For the sake of clarity the period sign is not used in these *Tables*
$:b = c$	$a:b$, read as 'a divided by b', denotes division. a is the dividend, b the divisor; $a:b$, or c, is the quotient. Division is the opposite of multiplication and can also be represented by the fraction $\frac{a}{b}$ or a/b. In fractions, a is the numerator (= dividend), b the denominator (= divisor)
$^b = c$	a^b, read as 'a to the power b', is known as involution. a is the base, b the exponent; a^b, or c, is the bth power of a. In the special case of $a^2 = c$, a^2 or c is the square of a; in that of $a^3 = c$, a^3 or c is the cube of a
$\sqrt[b]{a} = c$	$\sqrt[b]{a}$, is the bth root of a, b being known as the exponent. In the special case of $\sqrt[2]{a} = c$, $\sqrt[2]{a}$ o known as the square root of a, and the root e nent is usually omitted, i.e., $\sqrt[2]{a} = \sqrt{a}$. In the sp case of $\sqrt[3]{a} = c$, $\sqrt[3]{a}$ or c is known as the cube root Extraction of a root is the opposite of involut See also 'Logarithms', page 134
log, ln	See 'Logarithms', page 134
e	Base of natural (napierian) logarithms $= 2.7182818284\ldots$
π	Ratio of the circumference of a circle to its diam $= 3.1415926535\ldots$
sin, cos, tan, tg	See page 138
arc sin	See page 139

II. Numbers

The *natural numbers* consist of all positive whole numbers (posit integers). Zero* and negative numbers are not natural numbers

The *rational numbers* consist of all positive and negative intege the fractions formed from them, and zero.

The *irrational numbers* are incommensurable quantities that c not be expressed as quotients either of integers or of ratio fractions. Examples are $\sqrt{2}$ and $\sqrt{5}$. π and e are also irrational nu bers.

The *real numbers* consist of all rational and irrational numbe The fundamental laws of real numbers are the following:

1. The four fundamental operations

Addition, subtraction, multiplication and division (except di sion by zero) can always and without ambiguity be carried o with real numbers.

2. The order of numbers

Between any two real numbers a and b there can exist *only one* the three relationships

$$a = b \quad \text{or} \quad a > b \quad \text{or} \quad a < b$$

where

$$a = b \quad \text{when} \quad a - b = 0 \qquad (1$$

$$a > b \quad \text{when} \quad a - b > 0 \qquad (2$$

$$a < b \quad \text{when} \quad a - b < 0 \qquad (3$$

Examples of inequalities (2) and (3) are

$$\cdots > \quad 10 > \quad 9 > \cdots > \quad 1 > 0 > -1 > \cdots > -10 > \cdots$$

$$\cdots < -10 < -9 < \cdots < -1 < 0 < \quad 1 < \cdots < \quad 10 < \cdots$$

3. The commutative law

$$a + b = b + a \qquad (4)$$

$$ab = ba \qquad (5)$$

4. The associative law

$$(a + b) + c = a + (b + c) \qquad (6)$$

$$(ab)c = a(bc) \qquad (7)$$

5. The distributive law

$$a(b + c) = ab + ac \qquad (8)$$

III. Calculations with zero and infinity

$$a - a = 0 \qquad (9)$$

$$\cdot 0 = 0 \qquad (10)$$

$$0 \times a = 0 \qquad (11)$$

* Some mathematicians regard zero also as a natural number.

$$\frac{a}{\infty} = 0 \quad (a \neq \infty) \tag{12}$$

$$\frac{0}{a} = 0 \quad (a \neq 0) \tag{13}$$

$$\frac{a}{0} \quad \text{not defined} \tag{14}$$

$$0^a = 0 \quad (a > 0) \tag{15}$$

$$a^0 = 1 \quad (a \neq 0) \tag{16}$$

$$\lim_{n \to \infty} a^n = \begin{cases} \infty & \text{for } a > 1 \\ 1 & \text{for } a = 1 \\ 0 & \text{for } -1 < a < 1 \text{ and } a \neq 0 \\ \text{nonconvergent} & \text{for } a \leq -1 \end{cases} \tag{17}$$

$$\log_c 0 = -\infty \quad (c > 1) \tag{18}$$

$$\log_c \infty = +\infty \quad (c > 1) \tag{19}$$

$$\log_c 1 = 0 \tag{20}$$

$$0! = 1 \tag{21}$$

$$\binom{n}{0} = 1 \tag{22}$$

IV. Addition, subtraction, multiplication, division

1. Algebraic signs

If a, b, c are positive numbers, then

$$a \pm b = a \mp (-b) \tag{23}$$

$$a(-b) = (-a)b = -(ab) = -c \tag{24}$$

$$(-a)(-b) = +ab = +c \tag{25}$$

$$\frac{-b}{a} = \frac{b}{-a} = -\frac{b}{a} = -c \tag{26}$$

$$\frac{-b}{-a} = +\frac{b}{a} = +c \tag{27}$$

2. Brackets

$$a - b - c - d - \cdots = a - (b + c + d + \cdots) \tag{28}$$

$$\pm ab \pm ac \pm ad \pm \cdots = a(\pm b \pm c \pm d \pm \cdots) = \pm a(b + c + d + \cdots) \tag{29}$$

3. Conversion of divisions into multiplications

$$\frac{b}{a} = \frac{1}{a} \times b \tag{30}$$

For values of $1/a$ for numbers from 1 to 999 see page 18. Equation (30) is particularly useful in mechanical calculation with a constant divisor.

4. Conversion of multiplications and divisions into additions

If b is an integer (or can be converted into an integer), then

$$\left.\begin{aligned} ab &= a + a + a + \cdots \\ \frac{b}{a} &= \frac{1}{a} + \frac{1}{a} + \frac{1}{a} + \cdots \end{aligned}\right\} b \text{ components} \tag{31}$$

Equation (31) is particularly useful in the mechanical tabulation of linear functions.

5. Fractions

$$\frac{a}{a} = 1 \quad (a \neq 0) \tag{32}$$

$$\frac{ma}{mb} = \frac{a}{b} \quad (m \neq 0) \tag{33}$$

$$\frac{a}{b} + \frac{c}{b} = \frac{a + c}{b} \quad \text{(can also be used from right to left)} \tag{34}$$

$$\frac{a}{b} + \frac{c}{d} = \frac{ad + bc}{bd} \quad \text{(can also be used from right to left)} \tag{35}$$

$$\frac{a}{b} \times \frac{c}{d} = \frac{a}{d} \times \frac{c}{b} = \frac{ac}{bd} \tag{36}$$

$$\frac{a}{b} : \frac{c}{d} = \frac{a}{b} \times \frac{d}{c} = \frac{a}{c} \times \frac{d}{b} = \frac{a}{c} : \frac{b}{d} \tag{37}$$

6. Proportions

The equation

$$a : b = c : d \tag{38}$$

read as 'a is to b as c is to d', is known as a proportion. a and d are the extremes, b and c the means of the proportion. The product of the extremes equals the product of the means

$$ad = bc \tag{39}$$

If a constant proportion is of the type expressed by

$$a : b = b : c \tag{40}$$

then in accordance with equation (39), $ac = b^2$, that is, $b = \sqrt{ac}$ (41)

b is known as the mean proportional between a and c, or the geometric mean of a and c. c is known as the third proportional to a and b.

A special case of proportions of type (40) is the so-called 'golden section' (extreme and mean ratio)

$$\left.\begin{aligned} &\frac{a}{b} = \frac{b}{a - b}, \text{ that is} \\ &b = \frac{a(\sqrt{5} - 1)}{2} = 0.618034\,a \quad \text{or} \quad \frac{a}{b} = 1.618034 \end{aligned}\right\} \tag{42}$$

Another special case is that of the so-called 'normal' format, expressed by

$$\left.\begin{aligned} &\frac{a}{b} = \frac{b}{a/2}, \text{ that is} \\ &b = a/\sqrt{2} = 0.707107\,a \quad \text{or} \quad \frac{a}{b} = 1.414214 \end{aligned}\right\} \tag{43}$$

If the individual values of two related variables x, y are such that

$$\frac{y_1}{x_1} = \frac{y_2}{x_2} = \frac{y_3}{x_3} = \cdots = k \tag{44}$$

then

$$y = kx \tag{45}$$

read as 'y is proportional to x in the ratio k'. k is known as the proportionality constant. As x increases, y increases in proportion when k is positive, decreases when k is negative. The graphical representation of a proportional relationship on rectangular coordinates results in a straight line, whence the expression linear relationship. On the other hand, a linear relationship between x and y does not necessarily mean that they are proportional to one another since there are many straight lines that do not correspond to equation (45). For example, $y = a + kx$ is *not* a proportional relationship between x and y. In this case $(y - a)$ is proportional to x.

If the individual values of two related variables x, y are such that

$$\left.\begin{aligned} &\frac{y_1}{1/x_1} = \frac{y_2}{1/x_2} = \frac{y_3}{1/x_3} = \cdots = k \\ &\text{that is} \\ &y_1 x_1 = y_2 x_2 = y_3 x_3 = \cdots = k \end{aligned}\right\} \tag{46}$$

then

$$y = \frac{k}{x} \tag{47}$$

read as 'y is inversely proportional to x in the ratio k'. The graphical representation of an inversely proportional relationship on rectangular coordinates results in a hyperbola. Such a relationship is therefore a nonlinear one.

V. Powers and roots

1. Powers with integral exponents

If a and b are any real numbers, m and r positive integers, then

$$0^m = 0 \quad (m > 0) \tag{48}$$

$$a^0 = 1 \quad (a \neq 0) \tag{16}$$

$$\lim_{(m \to \infty)} a^m = \begin{cases} \infty & \text{for } a > 1 \\ 1 & \text{for } a = 1 \\ 0 & \text{for } -1 < a < 1 \text{ and } a \neq 0 \\ \text{nonconvergent for } a \leqq -1 \end{cases} \tag{17}$$

$$a \times a \times a \times \cdots (m \text{ factors}) = a^m \tag{48}$$

$$\frac{1}{a} \times \frac{1}{a} \times \frac{1}{a} \times \cdots (m \text{ factors}) = \frac{1}{a^m} = a^{-m} \quad (a \neq 0) \tag{49}$$

$$a^m \times b^m = (a\,b)^m \tag{50}$$

$$\frac{a^m}{b^m} = \left(\frac{a}{b}\right)^m = a^m\,b^{-m} \quad (b \neq 0) \tag{51}$$

$$a^m \times a^r = a^{m+r} \tag{52}$$

$$\frac{a^m}{a^r} = a^m\,a^{-r} = a^{m-r} \quad (a \neq 0) \tag{53}$$

$$(a^m)^r = (a^r)^m = a^{mr} \tag{54}$$

Algebraic signs: If in equations (48) to (54) R is the resulting *absolute value* of the base, c the absolute value of the power, $2\,m$ or $2m-1$ the resulting even or uneven exponent, then

$$(\pm R)^{2m} = +c \tag{55}$$

$$(\pm R)^{2m-1} = \pm c \tag{56}$$

2. Extraction of roots with integral exponents

If a and b are any real numbers, n and s positive integers but not zero, then

$$\sqrt[n]{a} = a^{\frac{1}{n}} \tag{57}$$

$$\frac{1}{\sqrt[n]{a}} = a^{-\frac{1}{n}} \quad (a \neq 0) \tag{58}$$

$$\sqrt[n]{a\,b} = \sqrt[n]{a}\,\sqrt[n]{b} = (a\,b)^{\frac{1}{n}} \tag{59}$$

$$\sqrt[n]{\frac{a}{b}} = \frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \left(\frac{a}{b}\right)^{\frac{1}{n}} (b \neq 0) \tag{60}$$

$$\sqrt[s]{\sqrt[n]{a}} = \sqrt[n]{\sqrt[s]{a}} = a^{\frac{1}{ns}} \tag{61}$$

Algebraic signs: If in equations (57) to (61) R is the resulting *absolute value* of the base, c the absolute value of the power, $2n$ or $2n-1$ the resulting even or uneven exponent, then

$$\sqrt[2n]{(+R)} = (+R)^{\frac{1}{2n}} = +c \tag{62}$$

$$\sqrt[2n]{(-R)} = (-R)^{\frac{1}{2n}} \quad \text{has no real solution} \tag{63}$$

$$\sqrt[2n-1]{(\pm R)} = (\pm R)^{\frac{1}{2n-1}} = \pm c \tag{64}$$

3. Mixed powers and roots

If a and b are any real numbers, m and r positive integers, k, n and s likewise positive integers but not zero, then

$$\sqrt[n]{a^m} = a^{\frac{m}{n}} \tag{65}$$

$$\frac{1}{\sqrt[n]{a^m}} = a^{-\frac{m}{n}} \quad (a \neq 0) \tag{66}$$

$$\sqrt[kn]{a^{km}} = \sqrt[n]{a^m} = a^{\frac{m}{n}} \tag{67}$$

If in equation (67) a is negative it is important that all other necessary conversion operations on the exponent should be performed *before* reduction is carried out. If the resulting numerator in the exponent is even, then a negative a is made positive and reduction carried out.

$$\sqrt[n]{(a\,b)^m} = \sqrt[n]{a^m} \times \sqrt[n]{b^m} = (a\,b)^{\frac{m}{n}} \tag{68}$$

$$\frac{\sqrt[n]{a^m}}{\sqrt[n]{b^m}} = \sqrt[n]{\left(\frac{a}{b}\right)^m} = \left(\frac{a}{b}\right)^{\frac{m}{n}} (b \neq 0) \tag{69}$$

$$\sqrt[n]{a} \times \sqrt[s]{a} = a^{\frac{1}{n}+\frac{1}{s}} = a^{\frac{n+s}{ns}} = \sqrt[ns]{a^{n+s}} \tag{70}$$

$$\sqrt[n]{a^m} \times \sqrt[s]{a^r} = a^{\frac{m}{n}+\frac{r}{s}} = a^{\frac{ms+nr}{ns}} = \sqrt[ns]{a^{ms+nr}} \tag{71}$$

$$\left(a^{\frac{m}{n}}\right)^{\frac{r}{s}} = \left(a^{\frac{r}{s}}\right)^{\frac{m}{n}} = a^{\frac{mr}{ns}} \tag{72}$$

Algebraic signs: If in equations (65) to (72) R is the resulting *absolute value* of the base, c the absolute value of the power, $2m$, $2n$, or $2m-1$, $2n-1$ respectively the resulting even or uneven numerator and denominator of the exponent, then

$$\sqrt[2n]{(\pm R)^{2m}} = (\pm R)^{\frac{2m}{2n}} = (+R)^{\frac{2m}{2n}} = +c \tag{73}$$

(always to be used in any reduction of an exponent)

$$\sqrt[2n]{(+R)^{2m-1}} = (+R)^{\frac{2m-1}{2n}} = +c \tag{74}$$

$$\sqrt[2n]{(-R)^{2m-1}} = (-R)^{\frac{2m-1}{2n}} \quad \text{has no real solution} \tag{75}$$

$$\sqrt[2n-1]{(\pm R)^{2m}} = (\pm R)^{\frac{2m}{2n-1}} = +c \tag{76}$$

$$\sqrt[2n-1]{(\pm R)^{2m-1}} = (\pm R)^{\frac{2m-1}{2n-1}} = \pm c \tag{77}$$

VI. Logarithms

In accordance with the equation

$$a = c^{\log_c a} \tag{78}$$

(a = number or antilogarithm, c = base, $\log_c a$ = logarithm of a to the base c)

the logarithm of a to the base c is defined as the exponent of the power of the base c which equals the number a. The usual bases are 10 (common or briggsian logarithms) and $e = 2.718\,281\,828\,5$ (natural, napierian or hyperbolic logarithms). In these *Tables* the symbol log is used for common logarithms and the symbol ln for natural logarithms. The relation between the two is given by

$$\ln a = \frac{\log a}{\log e} = 2.302\,585\,093\,0 \log a = \ln 10 \times \log a \tag{79}$$

$$\log a = \frac{\ln a}{\ln 10} = 0.434\,294\,481\,9 \ln a = \log e \times \ln a \tag{80}$$

In general the relation is expressed by

$$\log_c a = \frac{\log_{10} a}{\log_{10} c} \tag{81}$$

Example: It is required to find the logarithm of 20 to the base 2. From equation (81)

$$\log_2 20 = \frac{\log_{10} 20}{\log_{10} 2} = \frac{1.301\,030\,0}{0.301\,030\,0} = 4.321\,928$$

The use of logarithms reduces multiplication, division, raising to powers and the extraction of roots to addition, subtraction, multiplication and division respectively.

For common logarithms equation (78) gives

$$a = 10^{\log a} \quad \text{and} \quad b = 10^{\log b}$$

so that according to equation (52)

$$a \times b = 10^{\log a} \times 10^{\log b} = 10^{\log a + \log b}$$

that is $\quad \log(a \times b) = \log a + \log b$

whence $\quad (a \times b) = \text{antilog}(\log a + \log b)$

All the principles of logarithmic calculation can be deduced from section V in an analogous manner. The most important are:

$$\log(a \times b) = \log a + \log b \tag{82}$$

$$\log\left(\frac{a}{b}\right) = \log a - \log b \tag{83}$$

$$\ldots^{b} = b \log a \qquad (84)$$

$$\sqrt[b]{a} = \frac{\log a}{b} \qquad (85)$$

…e by definition there are only logarithms of positive num… logarithmic calculation is made without regard to the alge… sign of $a, b, \ldots$ and the result assigned the appropriate sign …ing to the rules already given

…garithmic calculation falls into three parts.

…ding the logarithms
…erating with them according to the above rules
…ding the antilogarithms.

…ding the logarithm

…e number of which the logarithm is required is first con…d into a product as follows:

$$\ldots = 10^{x} \times \frac{a}{10^{x}} = K' \times M' \qquad (86)$$

determined for $|a| \geq 1$ by counting the number b of places to …eft of the decimal point, for $|a| < 1$ by counting the number …ciphers to the right of the decimal point, so that

$$\ldots = b - 1 \quad \text{when} \quad |a| \geq 1 \qquad (87)$$

$$\ldots = -b - 1 \quad \text{when} \quad |a| < 1 \qquad (88)$$

…mples

a	b	x	K'	$K' \times M'$
…566 3	4	3	10^{3}	$10^{3} \times 1\,5663$
1 2	1	0	10^{0}	$10^{0} \times 1\,2$
0 12	0	−1	10^{-1}	$10^{-1} \times 1.2$
0 00034	−3	−4	10^{-4}	$10^{-4} \times 3\,4$

…n accordance with equation (82)

$$\log a = \log(K' \times M') = \log K' + \log M' = K + M \qquad (89)$$

…is known as the characteristic, M as the mantissa of the loga…hm of a

For $M' < 1\,1$, round off M' to 5 significant places

For $M' \geq 1\,1$, round off M' to 4 significant places

…xample

log 1 0993 = ? log 1.5663 ≈ log 1.566 = ?

From the table on page 10

x	$\log x$		Proportional parts	
	6	9	3	6
109		0410	1	
15	1931			17

log 1 0993 = 0 0410 + 0 0001 = 0.0411

log 1 566 = 0 1931 + 0 0017 = 0 1948

Further examples

(a) log 3048 = log (10³ × 3.048)
= 3 + 0 4829 + 0.0011 = 3 4840

(b) log 0 2130 = log (10⁻¹ × 2.130)
= − 1 + 0.3284 …

(c) log 1/3048 = log (10⁻³ × 3 048⁻¹)
= − 3 − (0.4829 + 0 0011) = − 0 4840 − 3

(d) log 1/0 2130 = log (10¹ × 2.13⁻¹)
= 1 − 0 3284 = 0 6716

In example (c) the mantissa as well as the characteristic is negative A negative mantissa must be converted into a positive one by adding 1 to the mantissa and subtracting 1 from the characteristic For example:

$$-0\,4840 - 3 = \underbrace{-0\,4840 + 1}_{=0\,5160} \underbrace{-3 - 1}_{-4}$$

2. Operating with logarithms

This is done in accordance with equations (82) to (85) and the following rules·

…istic x gives the number b of places to the left of the decimal point (when $x \geq 0$) or the number b of ciphers to the right of the decimal point (when $x < 0$), as follows:

$$b = x + 1 \quad \text{when } x \geq 0 \qquad (90)$$

$$b = -(x + 1) \quad \text{when } x < 0 \qquad (91)$$

Examples

(a) $\log(3048 \times 0\,2130) = \dfrac{3.4840 \quad}{\underline{+0.3284-1}} = 2\,8124$
$3\,8124-1$

(b) $\log(0\,2130 : 3048) = \dfrac{0\,3284-1}{\underline{+0.5160-4}} = 0\,8444-5$
$0\,8444-5$

(c) $\log(0\,2130 : 0\,000\,3281) = \dfrac{0.3284-1}{-(0\,5160-4)}$
$= \dfrac{1.3284-2}{\underline{-0\,5160+4}} = 2.8124$
$0\,8124+2$

(d) $\log(0\,2130^{5}) = 5 \log 0\,2130 = 5 \times (0\,3284 - 1)$
$= 1\,6420 - 5 = 0\,6420 - 4$

(e) $\log(\sqrt[6]{0\,2130}) = \dfrac{\log 0\,2130}{6} = \dfrac{0\,3284-1}{6} = \dfrac{5\,3284-6}{6}$
$= 0\,8881 - 1$

(f) $\log(\sqrt[1.5]{0\,2130}) = \dfrac{\log 0\,2130}{1\,5} = \dfrac{0\,3284-1}{1.5} = \dfrac{0\,8284-1.5}{1.5}$
$= 0.5523 - 1$

3. Finding the antilogarithm

determined by means of equations (90) and (91)

Examples: antilog 2 8124 = 649 2
antilog (0 8881 − 1) = 0.7729
antilog (0 6420 − 4) = 0 0004385

VII. Factorials and binomial coefficients

1. $n^{(r)}$

For a positive integer r and any real number n the symbol $n^{(r)}$ represents the product

$$n^{(r)} = n(n-1)(n-2)\cdots(n-r+1) \qquad (92)$$

where

$$n^{(0)} = 1 \qquad (93)$$

Examples:

(a) $10^{(4)} = ?$

In this case, $(n - r + 1) = 10 - 4 + 1 = 7$, so that $10^{(4)} = 10 \times 9 \times 8 \times 7 = 5040$

(b) $4^{(5)} = ?$

In this case, $(n - r + 1) = 4 - 5 + 1 = 0$, so that $4^{(5)} = 4 \times 3 \times 2 \times 1 \times 0 = 0$

From example (b) it can be seen that

$$n^{(r)} = 0 \tag{94}$$

when $r > n$ and n is a positive integer.

2. Factorials

The factorial of a positive integer n, symbol $n!$, is defined as

$$n! = n(n-1)(n-2)\cdots 3 \times 2 \times 1 \tag{95}$$

where

$$0! = 1 \tag{96}$$

by definition.

For positive integers n, the factorial $n!$ can be expressed as $n^{(n)}$, in which case equation (92) can be written

$$n^{(r)} = \frac{n!}{(n-r)!} \tag{97}$$

Equations (93) and (94) remain valid.

Logarithms of the factorials of numbers n from 1 to 999 and of their reciprocals are given on pages 26 and 27. For the factorials of numbers $n \geqq 1000$ the STIRLING approximation is used:

$$\underset{(n \to \infty)}{n!} \to n^n e^{-n} \sqrt{2\pi n} \tag{98}$$

or

$$\log n! \to 0.5 \times [2n(\log n - 0.4342944819) + \log n + 0.798178] \tag{99}$$

3. Binomial coefficients

In its general form the binomial coefficient $\binom{n}{r}$ or $C(n,r)$ is defined as

$$\binom{n}{r} = \frac{n^{(r)}}{r!} \tag{100}$$

For $n^{(r)}$ and $r!$ see subsections 1 and 2 above.

When n is a positive integer equations (97) and (100) give

$$\binom{n}{r} = \frac{n!}{r!(n-r)!} \tag{101}$$

From equations (93), (94) and (96) it follows that

$$\binom{n}{0} = 1 \tag{102}$$

$$\binom{0}{0} = 1 \tag{103}$$

$$\binom{n}{r} = 0 \quad \text{when } r > n \text{ and } n \text{ is a positive integer.} \tag{104}$$

It is also clear that

$$\binom{n}{n} = 1 \tag{105}$$

Example: For $n = 9$ and $n = 10$ all the coefficients for values of r between zero and n are tabulated:

	r	0	1	2	3	4	5	6	7	8	9	
$n = 9$		1	9	36	84	126	126	84	36	9	1	
$n = 10$		1	10	45	120	210	252	210	120	45	10	1
	r	0	1	2	3	4	5	6	7	8	9	10

($n/2$ lies between $r = 4$ and $r = 5$ for $n = 9$, and at $r = 5$ for $n = 10$.)

It will be seen that as r increases, the values of $\binom{n}{r}$ increase up to $n/2$ and then decrease again in symmetrical fashion:

$$\binom{n}{r} = \binom{n}{n-r} \tag{106}$$

For uneven numbers n, the median falls between the two highest values of the series, for even numbers n it is at the highest value.

Binomial coefficients for n from zero to 39 and for r from zero to 15 are given on page 25. Logarithms of the binomial coefficients for n from 2 to 100 and for r from zero to $n/2$ are given on pages 70–77. For $101 \leqq n \leqq 999$ the binomial coefficients are calculated from equation (101) using the logarithms of factorials and their reciprocals given on pages 26 and 27.

VIII. Series

The sum $a_1 + a_2 + a_3 + \cdots + a_n$ of a sequence of numbers $a_1, a_2, a_3, \ldots a_n$ formed according to some fixed rule or law is known as a series.

1. Arithmetic series of the 1st order

This is a series in which the difference d between successive terms is constant:

$$a_2 - a_1 = a_3 - a_2$$

The individual terms are therefore

$$\left.\begin{matrix} a_1 & a_2 & a_3 & \cdots & a_n \\ a_1 & (a_1 + d) & (a_1 + 2d) & \cdots & a_1 + (n-1)d \end{matrix}\right\} \tag{107}$$

The sum of the first n terms is

$$S = \frac{n(a_1 + a_n)}{2} \tag{108}$$

A special case of (108) is the sum of the natural sequence of numbers $1, 2, 3, \ldots, n$

$$1 + 2 + 3 + \cdots + n = \frac{n(n+1)}{2} \tag{109}$$

Example: The sum of all numbers from 1 to 81 is

$(81 \times 82)/2 = 3321$

2. Geometric series

A geometric series is one in which there is a constant ratio q between successive terms

$$\left.\begin{matrix} a_1 & a_2 & a_3 & \cdots & a_n \\ a_1 & a_1 q & a_1 q^2 & \cdots & a_1 q^{n-1} \end{matrix}\right\} \tag{110}$$

The sum of the first n terms is

$$S = a_1 \frac{1 - q^n}{1 - q} = a_1 \frac{q^n - 1}{q - 1} \quad (q \neq 1) \tag{111}$$

When $-1 < q < 1$, $q^\infty = 0$ in accordance with (17), and (111) becomes

$$S_\infty = \frac{a_1}{1 - q} \quad (-1 < q < 1) \tag{112}$$

With the aid of equation (112) infinite periodic decimal fractions, for example, can be converted into true fractions.

Examples:

(a) $0.3333\dot{3} = \frac{3}{10} + \frac{3}{100} + \frac{3}{1000} \cdots$

$$q = \frac{1}{10} \qquad a_1 = \frac{3}{10}$$

$$0.3333\dot{3} = \frac{3}{10} \Big/ \frac{9}{10} = \frac{3}{9} = \frac{1}{3}$$

(b) $0.0333\dot{3} = \frac{3}{100} + \frac{3}{1000} + \cdots$

$$q = \frac{1}{10} \quad a_1 = \frac{3}{100}$$

$$0.0333\dot{3} = \frac{3}{100} \Big/ \frac{9}{10} = \frac{3}{90} = \frac{1}{30}$$

$$\text{(c) } 0.2333\dot{3} = \frac{2}{10} + \frac{3}{100} + \frac{3}{1000} + \cdots$$

The infinite series begins with 3/100, whence $q = 1/10$, $a_1 = 3/100$, etc., as in the previous example. There remains 2/10 to be added to it

$$0.2333\dot{3} = \frac{2}{10} + \frac{1}{30} = \frac{60+10}{300} = \frac{7}{30}$$

$$\text{(d) } 0.123123\dot{1}2\dot{3} = \frac{123}{1000} + \frac{123}{1000000} + \cdots$$

$$q = \frac{1}{1000} \quad a_1 = \frac{123}{1000}$$

$$0.\dot{1}2\dot{3} = \frac{123}{1000} \Big/ \frac{999}{1000} = \frac{123}{999} = \frac{41}{333}$$

Binomial series for positive integers n

$$\left.\begin{aligned}(a+b)^n = \binom{n}{0} a^n b^0 + \binom{n}{1} a^{n-1} b^1 + \binom{n}{2} a^{n-2} b^2 \\ + \binom{n}{3} a^{n-3} b^3 + \cdots + \binom{n}{n} a^0 b^n\end{aligned}\right\} \quad (113)$$

Algebraic signs: When b is negative, all terms in which the exponent of b is uneven are negative

Examples: $(a+b)^2 = a^2 + 2ab + b^2$

$(a+b)^3 = a^3 + 3a^2 b + 3ab^2 + b^3$ etc

IX. Means

For n positive variates $x_1, x_2, \ldots, x_n$

(a) the arithmetic mean $m_a = \dfrac{x_1 + x_2 + \ldots + x_n}{n} = \dfrac{\sum_1^n x_i}{n}$ (114)

(b) the geometric mean $m_g = \sqrt[n]{x_1 \times x_2 \times \ldots \times x_n}$ (115)

(c) the harmonic mean $m_h = 1 : \dfrac{1}{n}\left(\dfrac{1}{x_1} + \dfrac{1}{x_2} + \ldots + \dfrac{1}{x_n}\right)$ (116)

When $n = 2$, then

$$m_a = \frac{x_1 + x_2}{2} \quad (117)$$

$$m_g = \sqrt{x_1 x_2} \quad (118)$$

$$m_h = \frac{2 x_1 x_2}{x_1 + x_2} \quad (119)$$

CAUCHY's principle $m_a \geqq m_g \geqq m_h$ (120)

where the equality signs are valid only when

$x_1 = x_2 = \ldots = x_n$

X. Solutions of equations

Solutions of equations exist only when all the denominators differ from zero

Required is x

$$ax \pm b = 0, \quad x = \mp \frac{b}{a} \quad (121)$$

$$\frac{a}{x} \pm b = 0, \quad x = \mp \frac{a}{b} \quad (122)$$

1. Simplification of equations of higher degree

$$(ax \pm b)^m \pm c = 0, \quad x = \frac{\sqrt[m]{\mp c} \mp b}{a} \quad (123)$$

$$\sqrt[n]{ax \pm b} \pm c = 0, \quad x = \frac{(\mp c)^n \mp b}{a} \quad (124)$$

2. Equations of the first degree with two unknowns

x and y are required

$$a_1 x + b_1 y + c_1 = 0$$

$$a_2 x + b_2 y + c_2 = 0$$

$$x = \frac{b_1 c_2 - b_2 c_1}{a_1 b_2 - a_2 b_1}$$

$$y = -\frac{a_1 x + c_1}{b_1} = -\frac{a_2 x + c_2}{b_2}$$

3. Equations of the first degree with three unknowns

x, y, z are required:

$$a_1 x + b_1 y + c_1 z + d_1 = 0$$

$$a_2 x + b_2 y + c_2 z + d_2 = 0$$

$$a_3 x + b_3 y + c_3 z + d_3 = 0$$

Let

$$A = c_2 a_1 - c_1 a_2$$

$$B = c_2 b_1 - c_1 b_2$$

$$C = c_2 d_1 - c_1 d_2$$

$$D = c_3 a_2 - c_2 a_3$$

$$E = c_3 b_2 - c_2 b_3$$

$$F = c_3 d_2 - c_2 d_3$$

then

$$x = \frac{BF - CE}{AE - BD}$$

$$y = -\frac{C + Ax}{B} = -\frac{F + Dx}{E}$$

$$z = -\frac{a_1 x + b_1 y + d_1}{c_1} = -\frac{a_2 x + b_2 y + d_2}{c_2}$$

$$= -\frac{a_3 x + b_3 y + d_3}{c_3}$$

4. Quadratic equations with one unknown

$$ax^2 + bx + c = 0$$

$$x_{(1,2)} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-b}{2a} \pm \sqrt{\left(\frac{b}{2a}\right)^2 - \frac{c}{a}}$$

The magnitude $D = b^2 - 4ac$ is known as the discriminant of the equation. When

$D > 0$ there are two real solutions

$D = 0$ there is only one real solution

$D < 0$ there is no real solution

5. Exponential equations in common use

$x = 1 - e^{-\lambda}$, $\quad x = 1 - \text{antilog}(-0.4342944819\,\lambda)$

$a = 1 - e^{-z}$, $\quad z = -2.3025850930 \log(1 - a)$ $[0 \leqq a \leqq 1]$

If in equation (129)

$$z = \frac{a x^b \pm c}{d}, \text{ then } \log x = \frac{\log\left(\dfrac{dz \mp c}{a}\right)}{b}$$

(when $b = 1$ the log sign disappears on both sides)

$$z = \frac{a b^x \pm c}{d}, \text{ then } \quad x = \frac{\log\left(\dfrac{dz \mp c}{a}\right)}{\log b} \quad (b \neq 1)$$

$$z = \frac{d}{a x^b \pm c}, \text{ then } \log x = \frac{\log\left(\dfrac{d/z \mp c}{a}\right)}{b}$$

(when $b = 1$ the log sign disappears on both sides)

$$z = \frac{d}{ab^x \pm c}\text{, then } x = \frac{\log\left(\dfrac{d/z \mp c}{a}\right)}{\log b} \quad (b \neq 1) \qquad \textbf{(133)}$$

Equations (130) to (133) have no solution when

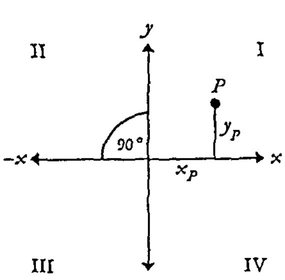
$(dz \mp c) < 0$ or $(d/z \mp c) < 0$

This is true for equations (130) and (132), however, only when $b \neq 1$.

The following table gives z values [solutions of equation (129)] for various numbers a in common use:

a	$1-a$	$\log(1-a)$	$z = -\ln 10 \times \log(1-a)$ $= -\ln(1-a)$
0.999	0.001	− 3	6.907 755 279
0.995	0.005	0.698 970 004 3 − 3	5.298 317 367
0.99	0.01	− 2	4.605 170 186
0.975	0.025	0.397 940 008 7 − 2	3.688 879 453
0.95	0.05	0.698 970 004 3 − 2	2.995 732 274
0.90	0.10	− 1	2.302 585 093
0.85	0.15	0.176 091 259 1 − 1	1.897 119 985
0.80	0.20	0.301 029 995 7 − 1	1.609 437 912
0.75	0.25	0.397 940 008 7 − 1	1.386 294 361
0.70	0.30	0.477 121 254 7 − 1	1.203 972 804
0.65	0.35	0.544 068 044 4 − 1	1.049 822 124
0.60	0.40	0.602 059 991 3 − 1	0.916 290 731 9
0.55	0.45	0.653 212 513 8 − 1	0.798 507 696 2
0.50	0.50	0.698 970 004 3 − 1	0.693 147 180 4
0.45	0.55	0.740 362 689 5 − 1	0.597 837 000 7
0.40	0.60	0.778 151 250 4 − 1	0.510 825 623 7
0.35	0.65	0.812 913 356 6 − 1	0.430 782 916 2
0.30	0.70	0.845 098 040 0 − 1	0.356 674 944 0
0.25	0.75	0.875 061 263 4 − 1	0.287 682 072 4
0.20	0.80	0.903 089 987 0 − 1	0.223 143 551 5
0.15	0.85	0.929 418 925 7 − 1	0.162 518 929 5
0.10	0.90	0.954 242 509 4 − 1	0.105 360 515 7
0.05	0.95	0.977 723 605 3 − 1	0.051 293 294 39
0.025	0.975	0.989 004 615 7 − 1	0.025 317 807 98
0.01	0.99	0.995 635 194 6 − 1	0.010 050 335 85
0.005	0.995	0.997 823 080 7 − 1	0.005 012 541 823
0.001	0.999	0.999 565 488 2 − 1	0.001 000 500 333

XI. Rectangular coordinate system



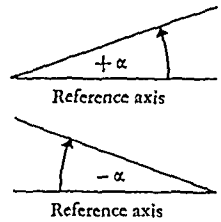
x axis	=	abscissa axis
y axis	=	ordinate axis
I, II, III, IV	=	quadrants
x_P and y_P	=	coordinates of the point P
x_P	=	abscissa of the point P
y_P	=	ordinate of the point P

Signs of the coordinates of points in each of the 4 quadrants

Quadrant	x	y
I	+	+
II	−	+
III	−	−
IV	+	−

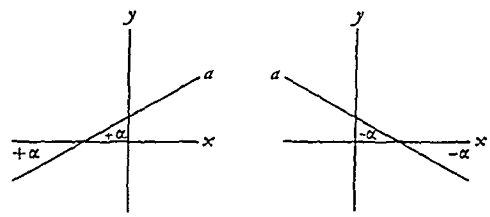
XII. Angles, trigonometric functions, inverse trigonometric functions

1. Positive and negative angles



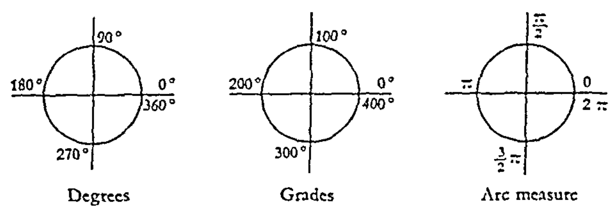
Rotation in an *anti*clockwise direction is defined as positive rotation, rotation in a clockwise direction as negative rotation. Similarly an angle measured by positive rotation is a positive angle, one measured by negative rotation a negative angle.

By angle of inclination of a straight line a is usually meant the *acute* angle between the straight line and the x axis.



2. Angle units (see also under 'Units of Measurement', page 207)

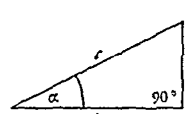
The basis of all angle units is the circumference of a circle drawn with its centre at the point of intersection of the lines forming the angle. This is divided into 360 equal parts (degrees, the unit normally used) or into 400 equal parts (grades), or measured in terms of its own radius (arc, circular or radian measure). Since the circumference of a circle is 2π times its radius, angles are often expressed as fractions or multiples of π. The arc measure of the angle α is designated arcus α (arc α).



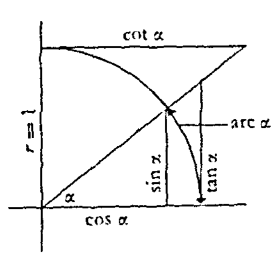
Degrees	0°	1°	30°	57°17′45″	60°	90°	180°	270°	360°
Arc measure	0	0.01745	$\frac{\pi}{6}$	1	$\frac{\pi}{3}$	$\frac{\pi}{2}$	π	$\frac{3}{2}\pi$	2π

3. Trigonometric functions (other than secant and cosecant)

The definitions are based on the right triangle and are valid only for acute angles between 0 and 90°:



$$\left.\begin{aligned}
&\text{sine } \alpha &&= \sin\alpha = \frac{a}{c}\\
&\text{cosine } \alpha &&= \cos\alpha = \frac{b}{c}\\
&\text{tangent } \alpha &&= \tan\alpha = \frac{a}{b}\\
&\text{cotangent } \alpha &&= \cot\alpha = \frac{b}{a}
\end{aligned}\right\} \qquad \textbf{(134)}$$



(the tangent is also sometimes abbreviated to tg, the cotangent to ctg or ctn)

Representation of trigonometric functions on the unit circle (circle with radius = 1)

Algebraic signs of trigonometric functions in the 4 quadrants

Function	*Quadrant* I	II	III	IV
sin	+	+	−	−
cos	+	−	−	+
tan	+	−	+	−
cot	+	−	+	−

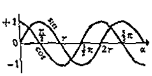
(135)

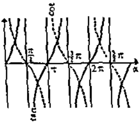
Ranges of trigonometric functions in the 4 quadrants

Function	Quadrant I	II	III	IV
sin	0 to 1	1 to 0	0 to −1	− 1 to 0
cos	1 to 0	0 to −1	−1 to 0	0 to 1
tan	0 to ∞	−∞ to 0	0 to ∞	−∞ to 0
cot	∞ to 0	0 to −∞	∞ to 0	0 to −∞

(136)

Behaviour of trigonometric functions





Functions of negative angles

$$\left.\begin{aligned}\sin(-\alpha) &= -\sin\alpha\\ \cos(-\alpha) &= +\cos\alpha\\ \tan(-\alpha) &= -\tan\alpha\\ \cot(-\alpha) &= -\cot\alpha\end{aligned}\right\}\quad(137)$$

Conversion of the functions of obtuse angles into those of acute angles

	90° ± α	180° ± α	270° ± α	n* (360°) ± α
sin	+ cos α	∓ sin α	− cos α	± sin α
cos	∓ sin α	− cos α	± sin α	+ cos α
tan	∓ cot α	± tan α	∓ cot α	± tan α
cot	∓ tan α	± cot α	∓ tan α	± cot α

(138)

* n = positive integer

Example sin 125° = cos 35°

Relationships between trigonometric functions

Function	sin α	cos α	tan α	cot α
sin α	$\sin\alpha$	$\pm\sqrt{1-\cos^2\alpha}$	$\dfrac{\tan\alpha}{\pm\sqrt{1+\tan^2\alpha}}$	$\dfrac{1}{\pm\sqrt{1+\cot^2\alpha}}$
cos α	$\pm\sqrt{1-\sin^2\alpha}$	$\cos\alpha$	$\dfrac{1}{\pm\sqrt{1+\tan^2\alpha}}$	$\dfrac{\cot\alpha}{\pm\sqrt{1+\cot^2\alpha}}$
tan α	$\dfrac{\sin\alpha}{\pm\sqrt{1-\sin^2\alpha}}$	$\dfrac{\pm\sqrt{1-\cos^2\alpha}}{\cos\alpha}$	$\tan\alpha$	$\dfrac{1}{\cot\alpha}$
cot α	$\dfrac{\pm\sqrt{1-\sin^2\alpha}}{\sin\alpha}$	$\dfrac{\cos\alpha}{\pm\sqrt{1-\cos^2\alpha}}$	$\dfrac{1}{\tan\alpha}$	$\cot\alpha$

(139)

Algebraic sign of the square root This is determined by the quadrant into which the angle falls For algebraic signs in the quadrants see (135)

Functions of half the angle and of twice the angle

$$\left.\begin{aligned}\sin\frac{\alpha}{2} &= \pm\tfrac{1}{2}\left(\sqrt{1+\sin\alpha}-\sqrt{1-\sin\alpha}\right)\\ &= \pm\sqrt{\frac{1-\cos\alpha}{2}}\end{aligned}\right\}\quad(140)$$

$$\cos\frac{\alpha}{2} = \pm\sqrt{\frac{1+\cos\alpha}{2}}\quad(141)$$

$$\left.\begin{aligned}\tan\frac{\alpha}{2} &= \frac{-1\pm\sqrt{1+\tan^2\alpha}}{\tan\alpha} = \frac{1-\cos\alpha}{\sin\alpha}\\ &= \frac{\sin\alpha}{1+\cos\alpha} = \pm\sqrt{\frac{1-\cos\alpha}{1+\sin\alpha}}\end{aligned}\right\}\quad(142)$$

$$\sin 2\alpha = 2\sin\alpha\cos\alpha\quad(143)$$

$$\cos 2\alpha = 2\cos^2\alpha - 1 = 1 - 2\sin^2\alpha = \cos^2\alpha - \sin^2\alpha\quad(144)$$

$$\tan 2\alpha = \frac{2\tan\alpha}{1-\tan^2\alpha}\quad(145)$$

Algebraic signs. ± *indicates that the algebraic sign is determined* by the quadrant into which the *required* angle falls For algebraic signs in the quadrants see (135).

Relationships between the functions of two angles

$$\sin(\alpha\pm\beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta\quad(146)$$

$$\cos(\alpha\pm\beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta\quad(147)$$

$$\mathrm{tg}(\alpha\pm\beta) = \frac{\mathrm{tg}\,\alpha\pm\mathrm{tg}\,\beta}{1\mp\mathrm{tg}\,\alpha\,\mathrm{tg}\,\beta} = \frac{\sin(\alpha\pm\beta)}{\cos(\alpha\pm\beta)}\quad(148)$$

$$\sin\alpha+\sin\beta = 2\sin\left(\frac{\alpha+\beta}{2}\right)\cos\left(\frac{\alpha-\beta}{2}\right)\quad(149)$$

$$\sin\alpha-\sin\beta = 2\cos\left(\frac{\alpha+\beta}{2}\right)\sin\left(\frac{\alpha-\beta}{2}\right)\quad(150)$$

$$\cos\alpha+\cos\beta = 2\cos\left(\frac{\alpha+\beta}{2}\right)\cos\left(\frac{\alpha-\beta}{2}\right)\quad(151)$$

$$\cos\alpha-\cos\beta = -2\sin\left(\frac{\alpha+\beta}{2}\right)\sin\left(\frac{\alpha-\beta}{2}\right)\quad(152)$$

$$\tan\alpha\pm\tan\beta = \frac{\sin(\alpha\pm\beta)}{\cos\alpha\cos\beta}\quad(153)$$

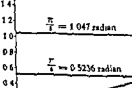
$$\sin\alpha\sin\beta = \tfrac{1}{2}\cos(\alpha-\beta) - \tfrac{1}{2}\cos(\alpha+\beta)\quad(154)$$

$$\cos\alpha\cos\beta = \tfrac{1}{2}\cos(\alpha-\beta) + \tfrac{1}{2}\cos(\alpha+\beta)\quad(155)$$

$$\sin\alpha\cos\beta = \tfrac{1}{2}\sin(\alpha+\beta) + \tfrac{1}{2}\sin(\alpha-\beta)\quad(156)$$

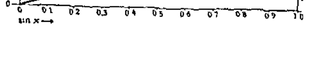
4. Inverse trigonometric functions

These are also known as arc or cyclometric functions Only th inverse sine (arc-sine) function will be described here, since this i used for the stabilization of the variance of binomial distribution (see page 187)



Arc sine x, abbreviated to $\sin^{-1}$ or arc sin x, is the arc or degree measure of the angle with *sine* = x A arc sine table in arc measure for th range $0 \leqq x \leqq 1$ is given on page 69 If the value of an arc sine in degree is required, the value given in th table must be multiplied by $180/\pi = 57\,295779513$

Behaviour of the function arc sin x in the range $0 \leqq x \leqq 1$



XIII. Hyperbolic functions

These derive their name from their geometric representation in relation to a rectangular hyperbola in a manner similar to that in which the trigonometric functions are related to a circle. Here only the hyperbolic tangent ($\tanh z$) and the corresponding inverse function ($\tanh^{-1} r$) will be dealt with, since these functions are required for the transformation of the correlation coefficient r (see page 180). They are defined as follows:

$$\tanh z = r = \frac{e^{2z} - 1}{e^{2z} + 1} \qquad (157)$$

$$\tanh^{-1} r = z = {}^1/_2 \ln \frac{1+r}{1-r} = 1.151\,292\,55 \log_{10} \frac{1+r}{1-r} \qquad (158)$$

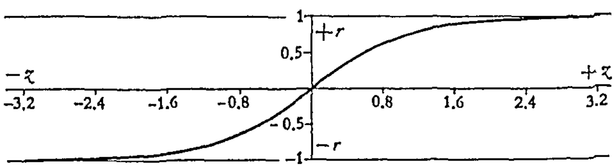
Only the following two relationships are required:

$$\tanh(-z) = -\tanh z \qquad (159)$$

$$\tanh^{-1}(-r) = -\tanh^{-1} r \qquad (160)$$

The range of variation of $\tanh z$ is -1 to $+1$ for values of z from $-\infty$ to $+\infty$.

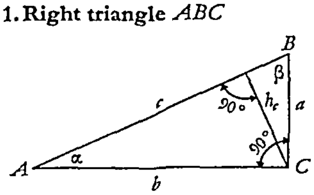
Behaviour of the function $\tanh z$ in the range $-3.2 \leq z \leq +3.2$



Tables of $\tanh z$ are given on pages 64 and 65, of $\tanh^{-1} r$ on page 62.

XIV. Geometric calculations

1. Right triangle ABC



a = perpendicular, b = base } sides

c = hypotenuse

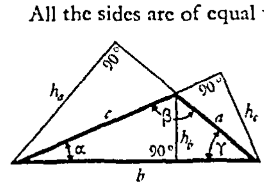
h_c = altitude above hypotenuse

Given	Required	Solution	
β	α	$= 90° - \beta$	(161)
a, b	α	$\tan\alpha = \frac{a}{b}$	(162)
	c	$= \frac{a}{\sin\alpha}$	(163)
		$= \frac{b}{\cos\alpha}$	(164)
		$= +\sqrt{a^2 + b^2}$	(165)
	h_c	$= a\cos\alpha$	(166)
		$= b\sin\alpha$	(167)
		$= \frac{ab}{c}$	(168)
	Area A	$= \frac{ab}{2}$	(169)
a, c	α	$\sin\alpha = \frac{a}{c}$	(170)
	b	$= c\cos\alpha$	(171)
		$= +\sqrt{c^2 - a^2}$	(172)

Given	Required	Solution	
a, c	Area A	$\frac{ac\cos\alpha}{2}$	(174)
b, c	α	$\cos\alpha = \frac{b}{c}$	(175)
	a	$= c\sin\alpha$	(176)
		$= +\sqrt{c^2 - b^2}$	(177)
	h_c	$= b\sin\alpha$	(178)
	Area A	$= \frac{bc\sin\alpha}{2}$	(179)
a, α	b	$= \frac{a}{\tan\alpha}$	(180)
	c	$= \frac{a}{\sin\alpha}$	(181)
	h_c	$= a\cos\alpha$	(182)
	Area A	$= \frac{a^2}{2\tan\alpha}$	(183)
c, α	a	$= c\sin\alpha$	(184)
	b	$= c\cos\alpha$	(185)
	h_c	$= \frac{c\sin 2\alpha}{2}$	(186)
	Area A	$= \frac{c^2\sin 2\alpha}{4}$	(187)
c, h_c	α	$\sin 2\alpha = \frac{2h_c}{c}$	(188)
	a	$= \frac{h_c}{\cos\alpha}$	(189)
	b	$= \frac{h_c}{\sin\alpha}$	(190)
	Area A	$= \frac{c\,h_c}{2}$	(191)

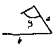
2. Obtuse triangle

All the sides are of equal value in the obtuse triangle, and permutation of a, b, c, etc. in a cyclic fashion results in different formulae which are equally valid. When one of the symbols in any formula in a group is permuted, the symbols in all the other formulae of the group must be permuted in accordance with the following scheme:



Permutation by one step	Permutation by two steps	
$a \rightarrow b$	$a \rightarrow c$	
$b \rightarrow c$	$b \rightarrow a$	
$c \rightarrow a$	$c \rightarrow b$	
$\alpha \rightarrow \beta$	$\alpha \rightarrow \gamma$	(192)
$\beta \rightarrow \gamma$	$\beta \rightarrow \alpha$	
$\gamma \rightarrow \alpha$	$\gamma \rightarrow \beta$	
. .	. .	

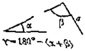
l areas	
$b \sin \gamma$	(193)
$c \sin \beta$	(194)
$a \dfrac{\sin \beta \sin \gamma}{\sin \alpha}$	(195)
$\dfrac{a h_a}{2}$	(196)

Given	Required	Solution	
	α	$= 180° - (\beta + \gamma)$	(197)
		$\sin(\beta+\gamma) = \sin\alpha$; $\cos(\beta+\gamma) = -\cos\alpha$; $\tan(\beta+\gamma) = -\tan\alpha$	(198)
	α	$\cos\alpha = \dfrac{b^2 + c^2 - a^2}{2bc}$	(199)
	h_a	$= b \sin\gamma$	(200)
		$= \dfrac{2A}{a}$	(201)
	Area A	$= \dfrac{bc \sin\alpha}{2}$	(202)
		$= \sqrt{s(s-a)(s-b)(s-c)}$	(203)
		where $s = \dfrac{a+b+c}{2}$	
	α	$\tan\alpha = \dfrac{a \sin\gamma}{b - a\cos\gamma}$	(204)
	c	$= \dfrac{a \sin\gamma}{\sin\alpha}$	(205)
		$= \sqrt{a^2 + b^2 - 2ab\cos\gamma}$	(206)
	h_a	$= b \sin\gamma$	(207)
	h_b	$= a \sin\gamma$	(208)
	Area A	$= \dfrac{ab \sin\gamma}{2}$	(209)
α 	β	$\sin\beta = \dfrac{b \sin\alpha}{a}$	(210)
	c	$= \dfrac{a \sin\gamma}{\sin\alpha}$	(211)
		$= b\cos\alpha \pm \sqrt{a^2 - b^2\sin^2\alpha}$	(212)
	h_a	$= b \sin\gamma$	(213)
	h_b	$= a \sin\gamma$	(214)
	h_c	$= b \sin\alpha$	(215)
	Area A	$= \dfrac{b}{2} \sin\alpha \times \left(b\cos\alpha \pm \sqrt{a^2 - b^2\sin^2\alpha}\right)$	(216)
b, β 	α	$\sin\alpha = \dfrac{a \sin\beta}{b}$	(217)
	c	$= \dfrac{b \sin\gamma}{\sin\beta}$	(218)
	h_a	$= b \sin\gamma$	(219)
	h_b	$= a \sin\gamma$	(220)

Given	Required	Solution	
a, b, β	h_c	$= a \sin\beta$	(221)
	Area A	$= \dfrac{a}{2} \sin\beta \times \left(a\cos\beta \pm \sqrt{b^2 - a^2\sin^2\beta}\right)$	(222)

Note that in the above group of equations (given two sides and the angle they enclose), the following conditions hold:

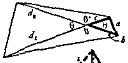
	Equations (210) – (216)	Equations (217) – (222)
Solution is only possible when	$b \sin\alpha \leq a$	$a \sin\beta \leq b$
If	$b \sin\alpha = a$	$a \sin\beta = b$
then	$\beta = 90°$	$\alpha = 90°$
If	$b \sin\alpha < a$ and $a < b$	$a \sin\beta < b$ and $b < a$
two solutions are possible	β_1 and $\beta_2 = 180° - \beta_1$	α_1 and $\alpha_2 = 180° - \alpha_1$
If	$b \sin\alpha < a$ and $a \geq b$	$a \sin\beta < a$ and $b \geq a$
no solution is possible.		

Given	Required	Solution	
a, β, γ  (Note that if two angles are given, the third is also given)  $\gamma = 180° - (\alpha + \beta)$	b	$= \dfrac{a \sin\beta}{\sin(\beta + \gamma)}$	(223)
	c	$= \dfrac{a \sin\gamma}{\sin(\beta + \gamma)}$	(224)
	h_a	$= \dfrac{a \sin\beta \sin\gamma}{\sin(\beta + \gamma)}$	(225)
	h_b	$= a \sin\gamma$	(226)
	h_c	$= a \sin\beta$	(227)
	Area A	$= \dfrac{a^2}{2} \times \dfrac{\sin\beta \sin\gamma}{\sin(\beta + \gamma)}$	(228)

3 Quadrilateral

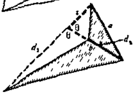
In general the area of any quadrilateral can be calculated from the diagonals and the angle θ (or $\theta' = 180° - \theta$) enclosed by them.

Any quadrilateral



$\sin\theta = \sin\theta'$

$$= \frac{2}{bc}\sqrt{s(s-a)(s-b)(s-c)} \quad (229)$$



Area of shaded part $= A$

where $s = \frac{1}{2}(a + b + c)$ is half the circumference of the triangle bounded by the two diagonals and the side a. Any triangle can be chosen, but the sides indicated by b, c must enclose the angle θ or θ'.

$$\text{Area } A = \frac{d_1 d_2 \sin\theta}{2} \quad (230)$$

Square

$d = a\sqrt{2} = 1.414214\,a$ (231)

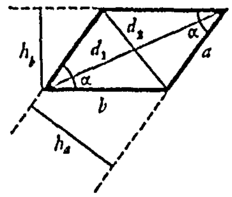
Area $A = a^2$ (232)

Rectangle

$d = \sqrt{a^2 + b^2}$ (233)

Area $A = ab$ (234)

Parallelogram



$$d_1, d_2 = \sqrt{a^2 + b^2 \pm 2ab\cos\alpha} \quad (235)$$

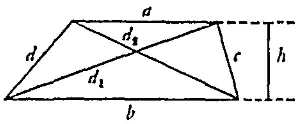
$$= \sqrt{a^2 + b^2 \pm 2a\sqrt{b^2 - h_a^2}} \quad (236)$$

$$h_a = b\sin\alpha \quad (237)$$

$$h_b = a\sin\alpha \quad (238)$$

$$\text{Area } A = a h_a = b h_b = a b \sin\alpha \quad (239)$$

Trapezoid



a, b are parallel, c, d nonparallel sides; d_1 = diagonal drawn between the points of intersection of d with b and a with c.

$$d_1 = \sqrt{ab + \frac{ac^2 - bd^2}{a - b}} \quad (240)$$

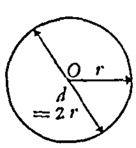
$$d_2 = \sqrt{ab + \frac{ad^2 - bc^2}{a - b}} \quad (241)$$

$$h = \frac{2}{a - b} \times \sqrt{s(s - a + b)(s - c)(s - d)} \quad (242)$$

where $s = \tfrac{1}{2}(a - b + c + d)$

$$\text{Area } A = \frac{(a + b)h}{2} \quad (243)$$

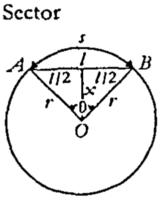
4. Circle



$$\left.\begin{aligned}\text{Circumference } c &= 2\pi r\\ &= 6.2831853\,r\\ &= 3.14159265\,d\end{aligned}\right\} \quad (244)$$

$$\left.\begin{aligned}\text{Area } A &= \pi r^2 = 3.14159265\,r^2\\ &= 0.785398\,16\,d^2\end{aligned}\right\} \quad (245)$$

Sector



Angle θ between the radii r

$$\cos\theta = 1 - \frac{l^2}{2r^2} \quad (246)$$

or

$$\theta = 180° - 2\arcsin(x/r) \quad (247)$$

Length of a chord

$$l = 2r\sin\frac{\theta}{2} \quad (248)$$

Length of an arc s

$$s = \frac{\pi r\theta}{180} = 0.017453293\,r\theta \quad (249)$$

Area of a sector

$$A_{Se} = \frac{\pi r^2\theta}{360} = 0.0087266463\,r^2\theta \quad (250)$$

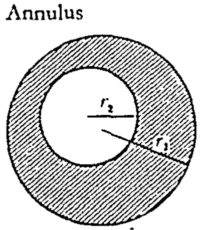
Area of a triangle OAB

$$A_\Delta = \frac{r^2\sin\theta}{2} \quad (251)$$

Area of a segment AsB

$$\left.\begin{aligned}A_{Sg} &= \frac{\pi r^2\theta}{360} - \frac{r^2\sin\theta}{2}\\ &= 0.0087266463\,r^2 \times\\ &\quad(\theta - 57.2957795\sin\theta)\end{aligned}\right\} \quad (252)$$

Annulus

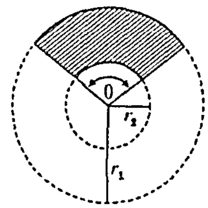


(The two circles bounding an annulus need not be concentric.)

Area of shaded part

$$\left.\begin{aligned}A &= \pi(r_1 + r_2)(r_1 - r_2)\ [r_1 \geqq r_2]\\ &= 3.14159265(r_1 + r_2)(r_1 - r_2)\end{aligned}\right\} \quad (253)$$

Annular segment (concentric)

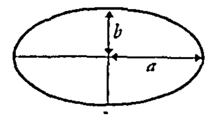


Area of shaded part

$$\left.\begin{aligned}A &= \frac{\pi\theta}{360}(r_1 + r_2)(r_1 - r_2)\ [r_1 \geqq r_2]\\ \frac{\pi}{360} &= 0.00872664626\end{aligned}\right\} \quad (254)$$

For the angle θ see equations (246) and (247).

5. Ellipse

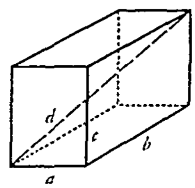


$$\left.\begin{aligned}\text{Circumference} &\sim 2\pi\sqrt{\frac{a^2 + b^2}{2}}\\ &\sim 4.443\sqrt{a^2 + b^2}\end{aligned}\right\} \quad (255)$$

$$\text{Area } A = \pi ab = 3.14159265\,ab \quad (256)$$

XV. Solid geometry

1. Rectangular parallelepiped (all edges at right angles to the adjacent ones)



Surface area

$$A = 2(ab + bc + ca) \quad (257)$$

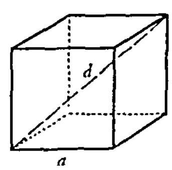
Internal diagonal

$$d = \sqrt{a^2 + b^2 + c^2} \quad (258)$$

Volume

$$V = abc \quad (259)$$

In the case of the cube, equations (257) to (259) become

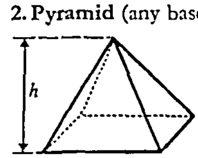


$$A = 6a^2 \quad (260)$$

$$d = a\sqrt{3} = 1.732051\,a \quad (261)$$

$$V = a^3 \quad (262)$$

2. Pyramid (any base)

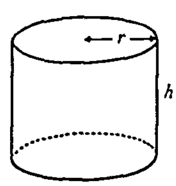


Volume

$$V = \frac{h}{3}A_B \quad (263)$$

(A_B = area of base)

3. Right circular cylinder



Area of convex surface

$$A_C = 2\pi rh = 6.2831853\,rh \quad (264)$$

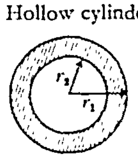
Total surface area

$$\left.\begin{aligned}A &= 2\pi r(r + h)\\ &= 6.2831853\,r(r + h)\end{aligned}\right\} \quad (265)$$

Volume

$$V = \pi r^2 h = 3.14159265\,r^2 h \quad (266)$$

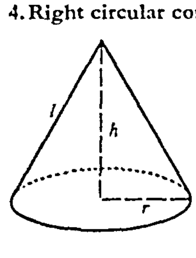
Hollow cylinder



Internal volume

$$\left.\begin{aligned}V_I &= \pi(r_1^2 - r_2^2)h\ [r_1 \geqq r_2]\\ &= 3.14159265(r_1^2 - r_2^2)h\end{aligned}\right\} \quad (267)$$

4. Right circular cone



Area of convex surface

$$\left.\begin{aligned}A_C &= \pi rl = 3.14159265\,rl\\ &(l = \text{slant height} = \sqrt{r^2 + h^2})\end{aligned}\right\} \quad (268)$$

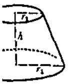
Total surface area

$$\left.\begin{aligned}A &= \pi r(r + l)\\ &= 3.14159265\,r(r + l)\end{aligned}\right\} \quad (269)$$

Volume

$$V = \frac{1}{3}\pi r^2 h = 1.04719755\,r^2 h \quad (270)$$

ted cone (right circular, plane surfaces parallel)



Area of convex surface

$$A_C = \pi l (r_1 + r_2) = 3.14159265\, l (r_1 + r_2) \qquad (271)$$

Total surface area

$$A = \pi\left[r_1(r_1 + l) + r_2(r_2 + l)\right] \qquad (272)$$

Volume

$$V = \frac{\pi h}{3}(r_1^2 + r_1 r_2 + r_2^2) = 1.047197551\, h(r_1^2 + r_1 r_2 + r_2^2) \qquad (273)$$

ere

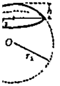
Surface area

$$A = 4\pi r^2 = \pi d^2 = 12.5663706\, r^2 = 3.14159265\, d^2 \qquad (274)$$

Volume

$$V = \frac{4\pi r^3}{3} = \frac{\pi d^3}{6} = 4.18879020\, r^3 = 0.52359878\, d^3 \qquad (275)$$

nt of a sphere (cut by a single plane)



Area of convex surface

$$A_C = \pi(r_1^2 + h^2) = 2\pi r_1 h \qquad (276)$$

Total surface area

$$A = \pi(2r_1^2 + h^2) \qquad (277)$$

Volume

$$V = \frac{\pi h}{6}(3r_1^2 + h^2) = \frac{\pi h^2}{3}(3r_1 - h) \qquad (278)$$

($\pi = 3.14159265$, $\pi/6 = 0.52359878$, $\pi/3 = 1.04719755$)

ent of a sphere (between two parallel planes)

Area of convex surface

$$A_C = 2\pi r_1 h = 6.2831853\, r_1 h \qquad (279)$$

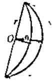
Total surface area

$$A = \pi(r_1^2 + 2r_1 h + r_2^2) \qquad (280)$$

Volume

$$V = \frac{\pi h}{6}(3r_1^2 + 3r_2^2 + h^2) = 0.52359878\, h(3r_1^2 + 3r_2^2 + h^2) \qquad (281)$$

e segment of a sphere

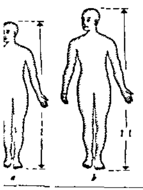


Volume

$$V = \frac{\pi r^3 \theta}{270} = 0.011635528\, r^3 \theta \qquad (282)$$

[for θ (= angle between the two planes passing through the centre of the sphere) see (246) and (247)]

dies of the same shape



Bodies of the same shape, i.e., those in which *all corresponding linear measurements bear the same ratio a:b**, have surface areas in the ratio $a^2:b^2$ and weights and volumes in the ratio $a^3:b^3$ (283)

All linear dimensions of body *b* are 10% greater than those of body *a*, *b* has 21% more surface area and 33% more weight

ote that this is usually not true of human bodies of different *heights*

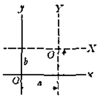
XVI. Formulae of analytical geometry

1. Transformation of rectangular coordinates

The new coordinates are indicated by *C*, the transformed variables by *X*, *Y*, the old coordinates and variables by *c*, *x*, *y*. For the sake of simplicity the transformation is illustrated in the first quadrant (see section XI, page 138) but the equations are valid for all quadrants.

(*a*) Translation of coordinate axes

The origin is translated from O to O′, i.e., a distance *a* in the direction *x* and a distance *b* in the direction *y*



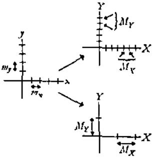
Transformation $c \rightarrow C$

$$X = x - a, \quad Y = y - b \qquad (284)$$

Transformation $C \rightarrow c$

$$x = a + X, \quad y = b + Y \qquad (285)$$

(*b*) Alteration of linear scale



Transformation $c \rightarrow C$

$$X = \frac{M_X}{m_x}x, \quad Y = \frac{M_Y}{m_y}y \qquad (286)$$

Transformation $C \rightarrow c$

$$x = \frac{m_x}{M_X}X, \quad y = \frac{m_y}{M_Y}Y \qquad (287)$$

(*c*) Translation of axes and alteration of linear scale

Transformation $c \rightarrow C$

$$X = \frac{M_X}{m_x}(x - a), \quad Y = \frac{M_Y}{m_y}(y - b) \qquad (288)$$

Transformation $C \rightarrow c$

$$x = a + \frac{m_x}{M_X}X, \quad y = b + \frac{m_y}{M_Y}Y \qquad (289)$$

(*d*) Rotation of coordinate axes

Transformation $c \rightarrow C$

$$X = x\cos\beta + y\sin\beta, \quad Y = y\cos\beta - x\sin\beta \qquad (290)$$

or

$$X = \frac{1}{\sqrt{1+\tan^2\beta}}(x + y\tan\beta), \quad Y = \frac{1}{\sqrt{1+\tan^2\beta}}(y - x\tan\beta) \qquad (291)$$

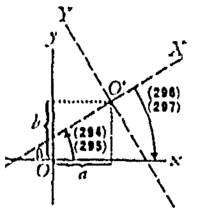
Transformation $C \rightarrow c$

$$x = X\cos\beta - Y\sin\beta, \quad y = X\sin\beta + Y\cos\beta \qquad (292)$$

or

$$x = \frac{1}{\sqrt{1+\tan^2\beta}}(X - Y\tan\beta), \quad y = \frac{1}{\sqrt{1+\tan^2\beta}}(Y + X\tan\beta) \qquad (293)$$

(*e*) Rotation and translation of the coordinate axes



Transformation $c \to C$

$$\left.\begin{aligned} X &= (x-a)\cos\beta + (y-b)\sin\beta \\ Y &= (y-b)\cos\beta - (x-a)\sin\beta \end{aligned}\right\} \qquad (294)$$

or

$$\left.\begin{aligned} X &= \frac{x-a+(y-b)\tan\beta}{\sqrt{1+\tan^2\beta}} \\ Y &= \frac{y-b-(x-a)\tan\beta}{\sqrt{1+\tan^2\beta}} \end{aligned}\right\} \qquad (295)$$

Transformation $C \to c$

$$\left.\begin{aligned} x &= a + X\cos\beta - Y\sin\beta \\ y &= b + Y\cos\beta + X\sin\beta \end{aligned}\right\} \qquad (296)$$

or

$$\left.\begin{aligned} x &= a + \frac{X - Y\tan\beta}{\sqrt{1+\tan^2\beta}} \\ y &= b + \frac{Y + X\tan\beta}{\sqrt{1+\tan^2\beta}} \end{aligned}\right\} \qquad (297)$$

2. Straight line

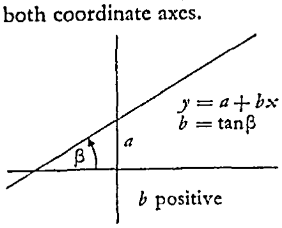
General equation

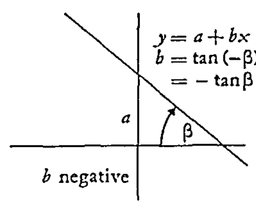
$$Ax + By + C = 0 \qquad (298)$$

Equation of slope

$$y = a + bx \quad \text{or} \quad x = \frac{y-a}{b} \qquad (299)$$

a = intercept with y axis, b = tangent of the angle of slope β. Note that $b = \tan\beta$ is valid *only* when the same unit is used for both coordinate axes.





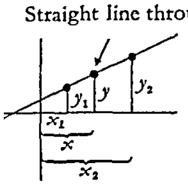
Special cases

$x = a$ is the equation of a line parallel to the y axis (300)

$y = c$ is the equation of a line parallel to the x axis (301)

A straight line is at right angles to another straight line with slope b when its slope is $-1/b$. (302)

Straight line through two points with coordinates x_1, y_1; x_2, y_2



$$y = y_1 + \frac{y_2 - y_1}{x_2 - x_1}(x - x_1) \qquad (303)$$

This formula is used for linear interpolation.

	x	y
Example: Tabulated values	110	83.83
	120	95.66

Required: the y value for $x = 116$

Solution: $y = 83.83 + \dfrac{95.66 - 83.83}{120 - 110}(116 - 110) = 90.93$

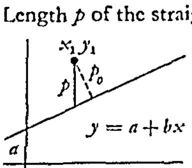
Straight line with slope b through a point x_1, y_1

$$y = y_1 + b(x - x_1) \qquad (304)$$

Straight line through the origin and a point x_1, y_1

$$y = \frac{y_1}{x_1}x \qquad (305)$$

Length p of the straight line parallel to the y axis between a point x_1, y_1 and the straight line $y = a + bx$

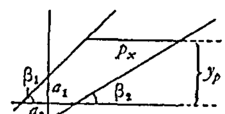


$$p = y_1 - a - bx_1 \qquad (306)$$

Shortest (orthogonal) distance p_0 between a point and the straight line $y = a + bx$

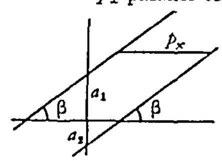
$$p_0 = \frac{y_1 - a - bx_1}{\sqrt{1+b^2}} \qquad (307)$$

Distance p_x parallel to the x axis at a height y_p between two straight lines $y = a_1 + b_1x$ and $y = a_2 + b_2x$



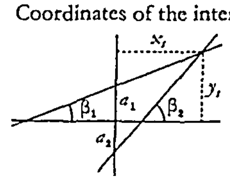
$$p_x = \left| \frac{y_p - a_1}{b_1} - \frac{y_p - a_2}{b_2} \right| \qquad (308)$$

Distance p_x parallel to the x axis between two parallel lines $y = a_1 + bx$ and $y = a_2 + bx$ [special case of (308) with $b_1 = b_2$]



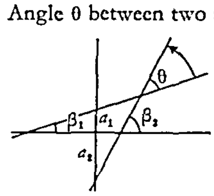
$$p_x = \left| \frac{a_1 - a_2}{b} \right| \qquad (309)$$

Coordinates of the intersection of two straight lines $y = a_1 + b_1x$ and $y = a_2 + b_2x$



$$\left.\begin{aligned} x_s &= \frac{a_2 - a_1}{b_1 - b_2} \\ y_s &= \frac{b_1a_2 - b_2a_1}{b_1 - b_2} \end{aligned}\right\} \qquad (310)$$

Angle θ between two straight lines with slopes b_1 and b_2

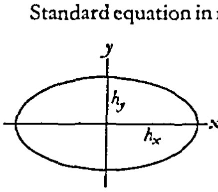


$$\tan\theta = \frac{b_1 - b_2}{b_1b_2 + 1} \qquad (311)$$

The angle θ is the positive angle through which the first straight line must be rotated in order that it shall coincide with the second straight line. Note that equation (311) is valid only when the same unit is used for both coordinate axes.

3. Ellipse

Standard equation in rectangular coordinates (the principal axes):



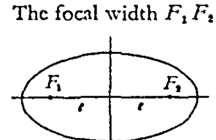
$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = c^2 \qquad (312)$$

a and b determine the relation between the two semi-axes and thus the shape of the ellipse.

If h_x is the semi-major, h_y the semi-minor axis, equation (312) becomes

$$\frac{x^2}{h_x^2} + \frac{y^2}{h_y^2} = 1 \quad \left\{ \begin{aligned} h_x^2 &= c^2a^2 \\ h_y^2 &= c^2b^2 \end{aligned} \right. \qquad (313)$$

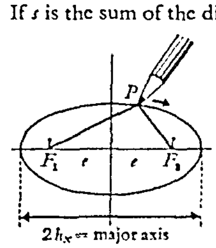
The focal width F_1F_2 is given by



$$2e = 2\sqrt{h_x^2 - h_y^2} \qquad (314)$$

e is known as the linear eccentricity.

If s is the sum of the distances from a point P on the curve to the foci F_1 and F_2, then



$$s = 2h_x = \text{major axis} \qquad (315)$$

Any desired ellipse may therefore be drawn by means of a thread of length $2h_x$ attached to the foci, e being determined from equation (314).

For area and circumference of the ellipse see equations (255) and (256) on page 142.

ts (pages 146–196)

(For references see page 196; for index see pages 197 and 198)

In the limited space here available it is impossible to give more than a brief explanation of the statistical tables on pages 10–131. The following description is therefore limited to those fundamentals the non-mathematician requires to enable him to solve simple statistical problems.

The calculation of probabilities by statistical methods is an essential step in the proper interpretation of experimental results that comply with certain basic laws but are at the same time subject to modification by unknown factors, in other words, to so-called 'chance' variation. This holds not only for the empirical sciences, the exact as well as the biological, but in a wider sense also for the abstract sciences:

On peut même dire à parler en rigueur, que presque toutes nos connaissances ne sont que probables; et dans le petit nombre des choses que nous pouvons savoir avec certitude, dans les sciences mathématiques elles-mêmes, les principaux moyens de parvenir à la vérité, l'induction et l'analogie, se fondent sur les probabilités... (LAPLACE, 1820)[1].

One reason for the physician's frequent mistrust of statistical methods is epitomized in the well-known allegation that 'you can prove anything with statistics'. Some prejudice against mathematics is also understandable in a profession in which intuitive reasoning is generally preferred. These are sentiments without any logical basis. Statistics is one of the most vigorous branches of mathematics, and its techniques for the disciplined assessment of observational data can be readily mastered. Furthermore, it should not be forgotten that every medical diagnosis represents the result of an intentional or unintentional calculation of probabilities.

This critical attitude towards statistics has its origin in their improper use as well as in their false interpretation. The statistical method is no more than another scientific method and cannot by its nature provide proof or disproof. On the other hand it constitutes the only method of subjecting values liable to chance variation (stochastic variables) to fixed and reproducible criteria based on logical mathematical considerations. The converse of the saying quoted is therefore much nearer the truth, namely that *no scientific investigation is capable of proving anything without the aid of statistics*. Human judgement is influenced to a very large extent by the subconscious wish and by the deep-rooted tendency – even in the worst of pessimists – to overrate one's own chances. The most careful investigator can be led astray by these psychological factors if he fails to arm himself against them with an adequate measure of self-control:

Le sentiment par lequel l'homme s'est placé longtemps au centre de l'univers en se considérant comme l'objet spécial des soins de la nature, porte chaque individu à se faire le centre d'une sphère plus ou moins étendue, et à croire que le hasard a pour lui des préférences. Soutenus par cette opinion, les joueurs exposent souvent des sommes considérables à des jeux dont ils savent que les chances leur sont contraires. Dans la conduite de la vie, une semblable opinion peut quelquefois avoir des avantages; mais le plus souvent elle conduit à des entreprises funestes. Ici, comme en tout, les illusions sont dangereuses et la vérité seule est généralement utile.

Un des grands avantages du Calcul des Probabilités est d'apprendre à se défier des premiers aperçus. Comme on reconnaît qu'ils trompent souvent lorsqu'on peut les soumettre au calcul, on doit en conclure que sur d'autres objets il ne faut s'y livrer qu'avec une circonspection extrême (LAPLACE, 1820)[1].

'The wish' as 'father to the thought' may be an indispensable stimulus to research, but it has also been responsible – in the guise of 'our experience' or 'our opinion' backed by a few percentages – for much misunderstanding. One need only reflect on the wealth of new treatments and new drugs which after an enthusiastic reception have been allowed to fall quietly into oblivion.

Many a research worker in the past could have spared himself much wasted time and effort had he submitted his observations and hypotheses to statistical test before publication. Recognition of this fact has clearly become general during the last decades, and close links have now been established between clinical medicine and statistics.

The growing use of statistical methods, however, is not without its own dangers. The general tendency is to overrate any new research tool, particularly when it is unfamiliar and complicated in operation. Too much uncritical dependence is placed on the results obtained; the limitations of the method may not be clearly recognized and the experimental data may be inadequately checked. Statistical methods obviously allow of no such dispensation. On the other hand, the beginner will find that with increasing experience statistical ways of thinking will not only render him more circumspect but give him a deeper insight.

1. Introductory definitions*

An experiment subject to chance factors may be compared to an operation such as the drawing of numbers in a lottery. Imagine a box containing balls bearing the numbers 0, 1, 2, . . ., 9. These are thoroughly mixed before the draw is commenced. The player drawing the balls is supposed to have no influence on the selection.

Using this analogy, we designate

– the mixing of the balls as the *randomization* of the experimental material; **(316)**

– the numbers 0, 1, 2, . . ., 9 distinguishing the balls as *variables* or *attributes*; **(317)**

– the aggregate number of balls in the box as the *parent population*; **(318)**

– a draw as a *trial*; **(319)**

– N trials as *random sampling*; **(320)**

– the result of the trial represented by the drawing of the number 5 as the *random event* 5; **(321)**

– the result of N trials as a *random sample* of size N, or briefly as a sample N; **(322)**

– the succession of events as a *random sequence* (in the numbered balls analogy it is the random series of numbers, or *random numbers*); **(323)**

– the relative frequency of the variate values in the population as the *probabilities* with which these values will be drawn; **(324)**

– the relative frequency of the variate values in the sample as *estimate* of their probability; **(325)**

– the distribution of the probabilities of the different variate values as probability distribution, or briefly as *distribution*. **(326)**

Some of these definitions will be discussed in more detail later in this chapter.

2. Population and sample

A population is finite or infinite when the trials (draws) can be repeated a finite or infinite number of times. **(327)**

A finite population, such as a finite number of balls in a box, can be converted into an effectively infinite one by putting the balls back into the box after each draw. Such an operation is known as *sampling with replacement*. **(328)**

From an infinite population an infinite number of samples can be taken, for example all of the same size N. The totality of such samples of size N is known as the *sampling population* N and their probability distribution as the *sampling distribution* N. **(329)**

An infinite sampling population can also be taken from a finite population in a manner similar to that in (328), i.e., by returning the whole of the first sample to the box, drawing a second sample of the same size, returning this sample also to the box, and so on. *All sampling populations can therefore be regarded as infinite*. This is one of the fundamental concepts of mathematical statistics. **(330)**

Quantities such as mean value and variance which relate to the population are known as *parameters*, their counterparts in the sample as *statistics*. **(331)**

Symbols relating to the population are here printed in bold type whenever it is necessary to distinguish them from symbols relating to samples. Exceptions are the symbols for mean value and variance: these are respectively μ and σ^2 for the population and $\bar{x}$ and s^2 for the sample. **(332)**

* The mathematician will appreciate that this presentation is more readily understandable by non-mathematicians than a strictly mathematical one.

iable and event

(333)

is an event, then the non-occurrence of A is its *mentary event*, designated here as non-A Examples ccess or failure, alive or dead, 6 or non-6 in die ring, etc. (334)

omplementary event non-A is often an event B For ple, a girl can be born instead of a boy Such events nown as *mutually exclusive events*, denoted by A or B, A, B A and non-A in (334) are therefore by defini- mutually exclusive events (335)

(336)

(337)

e occurrence (or non-occurrence) of an event A is cted by the condition that an event B has occurred occurs simultaneously, cf (336)], then event A is wn as a *conditioned event*, denoted by $A \mid B$ and read as t A under the condition B. B can represent several litions (338)

litative variables can be denoted by numbers, for nple 1 for success, 0 for failure (339)

e events are already numbers they are here denoted by ovided that other symbols are not in general use, as in case of some sampling distributions (340)

(within a finite interval) takes only a finite number of es it is known as a *discontinuous random variable* or *ate* In this case x changes by *discrete* amounts Exam- are 0, 1, 2, 3, successes, 25, 26, 27, respirations, (341)

he numbers 1, 2, 3, denote the smallest, second llest, third smallest value, etc , the series is known as ... their exact heights being known (342)

x can take all possible values in some interval it is wn as a *continuous random variable* or *variate* In this case hanges *continuously* Examples of continuous variates are gth, area, volume, weight, temperature, time and con- tration, i e , variables that can be *measured* (343)

practice, continuous variates do not exist since all mea- ed values are rounded values For example, when the allest interval a balance can measure is a milligramme, weight measured will be rounded off to the nearest (344)

the case of discrete variables the same value may occur (345)

two or more identical values occur in a sample of a anulated' variable they are known as *ties* or tied values (344) and (345) (346)

4. Frequency, probability, compound events

(34

to mean the relative frequency

The relative frequency multiplied by 100 is known as the *percentage frequency* *Example 2*. In 81 operations there are 3 fatalities The percentage frequency is then $(3/81) \times 100 = 3\ 7\%$. (34

The following symbols are used here for probability
'Probability' in general .... Prob
Probabilities of mutually exclusive events . $\dot{P}$
Probabilities of two complementary events . . p and q (34

In a later section the symbols α and P will also be used [cf (37 and (379)]

In (324) *probability* was defined as the *relative frequency of a variab* [or of an event, cf. (333)] *in the population* Propositions (350)-(35 follow directly from this definition

Every probability is a number between zero and one
$0 \leq \text{Prob} \leq 1$ (35

An impossible event has a probability of zero, a certain event a probability of one (351

The converse of (351) *is not valid*

An event with a probability of zero is an *almost* impossible event, an event with a probability of one an *almost* certain (352

The sum of the probabilities of *all* mutually exclusive events $E_0, E_1, \ldots, E_N$ in a single population is equal to one
$\text{Prob}(E_0 \text{ or } E_1 \text{ or } \ldots E_N)$
$= \dot{P}_0 + \dot{P}_1 + \ldots + \dot{P}_N = 1$
where the total of all mutually exclusive events is $N + 1$, and (cf. (335))
$\text{Prob}(E \text{ or non-}E) = p + q = 1$ (353

It follows from (353) that a population with many mutually exclusive events can be converted in various ways into one with two complementary events (354

For example

$$\text{Prob}\left[\underbrace{(E_0 \text{ or } E_1)}_{=E} \text{ or } \underbrace{(E_2 \text{ or } \ldots E_N)}_{=\text{non-}E}\right]$$
$$= \underbrace{(\dot{P}_0 + \dot{P}_1)}_{=p} + \underbrace{(\dot{P}_2 + \ldots + \dot{P}_N)}_{=q}$$

where the total number of mutually exclusive events is $N + 1$

an odd number likewise 1/2

From (353) it follows that

Of the mutually exclusive events $A, B, \ldots$, the probability that either the event A or the event B will occur is equal to the sum of their probabilities, *provided that the events are from one and the same population*
$\text{Prob}(A \text{ or } B \text{ or } \ldots) = \dot{P}_A + \dot{P}_B + \ldots$ (355)

Example 6 [of (355)] *Incorrect application* Assuming that the mortality of 85-year-olds is 0 5 and that of 86-year-olds 0 6, then

the statement that there is a 1.1 probability of an 85-year-old dying either at 85 or at 86 is false. Here the error is already indicated by the probability figure of 1.1, which according to (350) is an impossibility, but it might well have been overlooked had the figure been 0.4, as in example 5. The error arises from the fact that mutually exclusive events from *different* populations, that of the 85-year-olds and that of the 86-year-olds, have been added together.

The probability of two simultaneous or successive events A and B is equal to the probability of the event A multiplied by the probability of the event B under the condition A, or to the probability of the event B multiplied by the probability of the event A under the condition B. On conditioned events see (338).
$$\begin{aligned}\text{Prob}\,(A \text{ and } B) &= \text{Prob}\,(A) \times \text{Prob}\,(B \mid A)\\ &= \text{Prob}\,(B) \times \text{Prob}\,(A \mid B)\end{aligned} \qquad (356)$$

Example 7 [of (356)]. A box contains N balls, x red and $N-x$ white. A sample consisting of two balls is drawn *without replacement*. What is the probability of drawing (*a*) two red balls, (*b*) a red and then a white ball, (*c*) a red and a white ball in any order?

(*a*) The probability of a red ball at the first draw is x/N. The conditioned probability of a red ball at the second draw (when there is one red ball less in the box) is $(x-1)/(N-1)$. The probability of drawing two red balls is therefore

$$\text{Prob (red, red)} = \frac{x}{N} \times \frac{x-1}{N-1}$$

$$(b)\ \text{Prob (red, white)} = \frac{x}{N} \times \frac{N-x}{N-1} = \frac{N-x}{N} \times \frac{x}{N-1} = \text{Prob (white, red)}$$

(*c*) Prob (red and white) or Prob (white and red)
$= \text{Prob (red, white)} + \text{Prob (white, red)}$
$= 2x(N-x)/N(N-1)$

Example 8 [of (356)]. From the same box as in example 7 a sample of the same size is taken, but *with replacement*. In this case the probabilities are as follows:

(*a*) The probability of a red ball at the first draw remains x/N. Since this ball is replaced in the box, the probability of a red ball at the second draw is the same:

$$\text{Prob (red, red)} = \frac{x}{N} \times \frac{x}{N}$$

$$(b)\ \text{Prob (red, white)} = \frac{x}{N} \times \frac{N-x}{N} = \frac{N-x}{N} \times \frac{x}{N} = \text{Prob (white, red)}$$

(*c*) Prob (red and white) or Prob (white and red)
$= \text{Prob (red, white)} + \text{Prob (white, red)}$
$= 2x(N-x)/N^2$

From example 7 it will be seen that the probabilities change with each draw, i.e., each successive draw is *dependent* on the previous one. The corresponding statistical expressions are *dependent trials* and *dependent events*. In example 8 the second draw is unaffected by the previous one, in which case the trials and events are *independent*.

In other words, in the collection of samples from *finite* populations (no replacement), the trials and events are *dependent* on one another; in the collection of samples from *infinite* populations (replacement), they are *independent* of one another. (357)

Two simultaneous or successive events are known as stochastically *dependent* events when in (356) the conditioned and the absolute probability of an event are *not the same*, i.e., when
$\text{Prob}\,(A \mid B) \neq \text{Prob}\,(A)$, or $\text{Prob}\,(B \mid A) \neq \text{Prob}\,(B)$. (358)

Two simultaneous or successive events are known as stochastically *independent* events when in (356) the conditioned and the absolute probability of an event are *the same*, i.e., when
$\text{Prob}\,(A \mid B) = \text{Prob}\,(A)$, or $\text{Prob}\,(B \mid A) = \text{Prob}\,(B)$. (359)

From (356) and (359) it follows that the two events A and B are stochastically independent of one another when the probability of their simultaneous or successive occurrence is equal to the product of their probabilities:
If $\text{Prob}\,(A \text{ and } B) = \text{Prob}\,(A) \times \text{Prob}\,(B)$
then A and B are stochastically independent of one another. (360)

In (358)–(360) the expressions 'dependent' and 'independent' are coupled with the qualification 'stochastic'. This is a precautionary measure of the statistician. *In (358)–(360) a factual conclusion is reached on the basis of a mathematical result.* If such conclusions lie wholly within the domain of the probability calculation the expressions 'dependent' and 'independent' are completely valid, as in examples 7 and 8 under (356). However, if they are extended beyond the mathematical domain into those of physics, chemistry, physiology, etc., then the qualification 'stochastic' is necessary since the conceptions 'dependent' and 'independent' do not necessarily imply a *causal* connection. Stochastically independent events can very well be dependent on one another in reality. *The conclusion 'independent' implies only actual independence of the events.* It can be accepted if it is not incompatible with the physical circumstances. *On the other hand it can be regarded as proof* if independence were *presumable* from the physical circumstances and the mathematical treatment led to the *same* result. For this reason the converse of (360) should also be noted:

If A and B are events independent of one another, then the probability of their simultaneous or successive occurrence is equal to the product of their probabilities:
$\text{Prob}\,(A \text{ and } B) = \text{Prob}\,(A) \times \text{Prob}\,(B)$
(*when* A and B are independent of one another).

Example 9 [of (362)]. A box contains the events '+' and ' equal numbers, so that the probabilities are 1/2. Samples ar lected with replacement, so that in accordance with (357) the e are independent of one another. What is the probability of dra a '+' 5, 6 or 7 times in succession? The respective probabiliti $(1/2)^5$, $(1/2)^6$, $(1/2)^7$, or 0.03125, 0.015625, 0.0078125.

Example 10 [of (362)]. An infinite population contains the e A and B with the probabilities p and q respectively. What ar probabilities of the events AA, AB, BA, BB in two draws?

Event	Probability		
AA	$p \times p$	$= p^2$	$= p^2 + 2pq + q^2 = (p +$
AB	$p \times q$	$= 2pq$	$= 1^2 = 1$, as it should be according to (353)
BA	$q \times p$		
BB	$q \times q$	$= q^2$	

In the expression $p^2 + 2pq + q^2$ the individual terms resent the *probability distribution* for the events two As, one A, no As (provided that no importance is attached to the order in event one A). A *sampling distribution* [cf. (329)] is thus obtained samples of size 2 from an infinite population, the complemen variables A or B, and the probabilities p and q. From this exan it will be seen intuitively how samples with 3, 4, ... draws car dealt with: the sampling distributions can be written in accorda with (113) as developments of $(p+q)^3$, $(p+q)^4$, ... Cf. Binor distribution, page 183.

5. Discrete probability distribution

Example 10 under (362) demonstrated a simple sampling dis bution of practical importance that will be further discussed l in this chapter. At this point, discussion will be limited to a conceptions related to such a distribution.

Given an infinite population with the events $x = 0, 1, 2, \ldots$, and the probabilities $\dot{P}_x$, then:

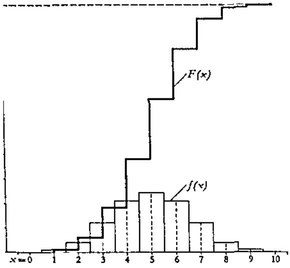
x	$\dot{P}_x = f(x)$	$\sum_{k=0}^{k=x} \dot{P}_k = F(x)$
0	0.0010	$0.0010 = \dot{P}_0$
1	0.0098	$0.0108 = \dot{P}_0 + \dot{P}_1$
2	0.0439	$0.0547 = \dot{P}_0 + \dot{P}_1 + \dot{P}_2$
3	0.1172	$0.1719 = \dot{P}_0 + \dot{P}_1 + \dot{P}_2 + \dot{P}_3$
4	0.2051	0.3770 etc.
5	0.2460	0.6230
6	0.2051	0.8281
7	0.1172	0.9453
8	0.0439	0.9892
9	0.0098	0.9990
10	0.0010	1.0000

e column $\dot{P}_x = f(x)$ gives the probabilities for the events), $x = 1$, $x = 2$, etc :

rding to (326) this is the *probability distribution* for the s $x = 0$, $x = 1$, $x = 2$, etc, denoted by $f(x)$. (363)

[illegible] (364)

iese data may be represented graphically:



1 Abscissae x, ordinates probabilities $f(x)$ and $F(x)$

Since x is a discrete variable [cf. (341)] the distributions $f(x)$ and x) give stepped curves. It follows that

discrete random variable has a discrete probability distribution (365)

ie probabilities are dependent on x, i e, *for every value of there is a definite probability* $f(x)$ and $F(x)$ are *functions* of whence the use of the symbols f and F (the Greek ters φ and Φ are also frequently used) The pattern of obabilities can be expressed by a mathematical formula in some other appropriate manner (366)

In Figure 1 the probabilities $f(x)$ and $F(x)$ are shown as stepped ies in order to emphasize the similarity between discrete and ntinuous distributions (cf Fig 8) In fact, such a stepped curve uld represent a *'granulated'* distribution [cf (344)] in which the lues of x have been rounded off to whole numbers In this case l events between 4 5 and 5 5, for example, would be assigned to ent 5 For this reason, another method is preferred here for presenting discrete distributions which shows clearly that the ents x are *discrete*

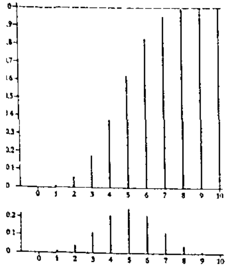


Fig 2

In the cumulative distribution $F(x)$ representing the probabilities of the events $x = 0$, $x = 0$ or 1, $x = 0$ or 1 or 2, etc, the expression $x = 0, 1$ will in future be used in place of $x = 0$ or 1. Prob $(x = 0, 1)$ can also be written as Prob $(x \leq 1)$ From (364) another notation is Prob $(x < 2, 3, \ldots, N)$, equivalent to Prob $(x < 2)$

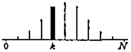
In general, the following expressions are valid for such discrete distributions.

$$\left.\begin{aligned}&\text{Prob}\,(x < k+1) = \text{Prob}\,(x \leq k), \quad \text{or}\\&\text{Prob}\,(x < k) = \text{Prob}\,(x \leq k-1)\\\text{and }&\text{Prob}\,(x > k-1) = \text{Prob}\,(x \geq k), \quad \text{or}\\&\text{Prob}\,(x > k) = \text{Prob}\,(x \geq k+1)\end{aligned}\right\} \quad (367)$$

With increasing values of k, the distribution $F(x)$ thus produces continuously the probabilities for $x \leq k$ or $x < k+1$. (368)

Conversely, with decreasing values of k the cumulative distribution $\sum_{x=k}^{N} \dot{P}_x$ from N in the direction of zero produces continuously the probabilities for $x \geq k$ or $x > k-1$ (369)

For discrete distributions in general the following should be noted:



$$\text{Prob}\,(x = k) = \dot{P}_k = f(k) \quad (370)$$

$$\text{Prob}\,(x \neq k) = 1 - \dot{P}_k = 1 - f(k) \quad (371)$$

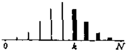
$$\text{Prob}\,(x \leq k) = \text{Prob}\,(x < k+1) \quad (372)$$

$= \sum_{0}^{k} \dot{P}_x$, best formula if $k \leq N/2$ (a)

$= 1 - \sum_{k+1}^{N} \dot{P}_x$, best formula if $k \geq N/2$ (b)

$= F(x)$, best formula if $F(x)$ is given (c)

$= 1 - \sum_{k+1}^{N} \dot{P}_x$, best formula if $\sum_{x}^{N} \dot{P}_x$ is given (d)



$$\text{Prob}\,(x \geq k) = \text{Prob}\,(x > k-1) \quad (373)$$

$= 1 - \sum_{0}^{k-1} \dot{P}_x$, best formula if $k \leq N/2$ (a)

$= \sum_{k}^{N} \dot{P}_x$, best formula if $k \geq N/2$ (b)

$= 1 - F(k-1)$, best formula if $F(x)$ is given (c)

$= \sum_{k}^{N} \dot{P}_x$, best formula if $\sum_{x}^{N} \dot{P}_x$ is given (d)

$$\left.\begin{aligned}&\text{Prob}\,(k \leq x \leq s) = \text{Prob}\,(x = k, l, \ldots, s)\\&= \text{Prob}\,(k-1 < x < s+1)\end{aligned}\right\} \quad (374)$$

$= \sum_{k}^{s} \dot{P}_x$, best formula if $s - k \leq N/2$ (a)

$= 1 - \sum_{0}^{k-1} \dot{P}_x - \sum_{s+1}^{N} \dot{P}_x$, best formula if $s - k \geq N/2$ (b)

$= F(s) - F(k-1)$, best formula if $F(x)$ is given (c)

$= \sum_{k}^{N} \dot{P}_x - \sum_{s+1}^{N} \dot{P}_x$, best formula if $\sum_{x}^{N} \dot{P}_x$ is given (d)

$$\left.\begin{aligned}&\text{Prob}(x \leqq k-1) + \text{Prob}(x \geqq s+1)\\ &= \text{Prob}(x < k) + \text{Prob}(x > s)\end{aligned}\right\} \quad (375)$$

$$= 1 - \sum_{k}^{s} \dot{P}_x, \text{ best formula if } s-k \leqq N/2 \qquad (a)$$

$$= \sum_{0}^{k-1} \dot{P}_x + \sum_{s+1}^{N} \dot{P}_x, \text{ best formula if } s-k \geqq N/2 \qquad (b)$$

$$= 1 - F(s) + F(k-1), \text{ best formula if } F(x) \text{ is given} \qquad (c)$$

$$= 1 - \sum_{k}^{N} \dot{P}_x + \sum_{s+1}^{N} \dot{P}_x, \text{ best formula if } \sum_{x}^{N} \dot{P}_x \text{ is given} \qquad (d)$$

In **(370)–(375)** the best formulae for use in each particular case are indicated. As a rule, the user must calculate $\dot{P}_x$ himself and then proceed with the formulae (a) or (b). The editors know of extensive tabulations of $\sum_{x}^{\infty} \dot{P}_x$ only for the POISSON distribution [2], of $\sum_{x}^{N} \dot{P}_x$ only for the binomial distribution [3,4], of $\sum_{0}^{x} \dot{P}_x \mid N, n, k$ only for the hypergeometric probability distribution [5]. Some publications [2,3,5] include also tabulated values of $f(x)$.

Example 11. Using the formulae (a) or (b) in **(370)–(375)**, the probabilities for $k = 2$ and $s = 8$ are calculated from the values of $f(x)$ given in the table on page 148.

(370): $\text{Prob}(x = 2) = \dot{P}_2 = 0.0439$

(371): $\text{Prob}(x \neq 2) = 1 - \dot{P}_2 = 0.9561$

(372): $\text{Prob}(x \leqq 2) = \dot{P}_0 + \dot{P}_1 + \dot{P}_2 = 0.0547$
[by formula (a), since $k < N/2$]

(373): $\text{Prob}(x \geqq 2) = 1 - (\dot{P}_0 + \dot{P}_1) = 0.9892$
[by formula (a), since $k < N/2$]

(374): $\text{Prob}(2 \leqq x \leqq 8) = \text{Prob}(x = 2, 3, \ldots, 8)$
$= 1 - (\dot{P}_0 + \dot{P}_1) - (\dot{P}_9 + \dot{P}_{10}) = 0.9784$
[by formula (b), since $s - k > N/2$]

(375): $\text{Prob}(x \neq 2, 3, \ldots, 8) = (\dot{P}_0 + \dot{P}_1) + (\dot{P}_9 + \dot{P}_{10}) = 0.0216$
[by formula (b), since $s - k > N/2$]

Example 12. What is the probability of the event 'x at least equal to 1'? This is the same as saying 'x equal to 1 or more' (cf. page 132), and calculation using **(373a)** gives

$\text{Prob}(x \geqq 1) = 1 - \dot{P}_0 = 0.9990$

Example 13

Confidence intervals* and significance limits
(Cf. also sections 8 and 9, pages 154–159)

A. One-sided significance limits

Given α, where $0 < \alpha \leqq 0.5$, determine x_l and x_r in such a way that

$$\left.\begin{aligned}&\text{Prob}(x \leqq x_l) = P_l = \sum_{0}^{x_l} \dot{P}_x \leqq \alpha \quad \text{and}\\ &\text{Prob}(x \leqq x_l + 1) = \sum_{0}^{x_l+1} \dot{P}_x > \alpha\end{aligned}\right\} \quad (376)$$

$$\left.\begin{aligned}&\text{Prob}(x \geqq x_r) = P_r = \sum_{x_r}^{N} \dot{P}_x \leqq \alpha \quad \text{and}\\ &\text{Prob}(x \geqq x_r - 1) = \sum_{x_r-1}^{N} \dot{P}_x > \alpha\end{aligned}\right\} \quad (377)$$

For $\alpha = 0.10$, $x_l = 2$ and $x_r = 8$; for $\alpha = 0.025$, $x_l = 1$ and $x_r = 9$.

The following definitions follow from the above example:

α is the *postulated* or *nominal one-sided significance probability* **(378)**

P is the *actual one-sided significance probability*, P_l being the *left* (*lower*) and P_r the *right* (*upper*) level, with P_l and $P_r \leqq \alpha$ **(379)**

x_l is the *left* (*lower*) and x_r the *right* (*upper*) significance limit **(380)**

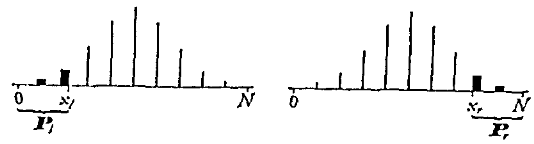


Fig. 3. One-sided significance limits of discrete distributions.

It should be noted that

– if x *attains or exceeds* (to the left) the *left* (lower) significance limit x_l, then in a *one-tailed* test
$\text{Prob}(x \leqq x_l) \leqq \alpha = \text{Prob}(x < x_{l+1})$ **(3**

– if x *attains or exceeds* (to the right) the *right* (upper) significance limit x_r, then in a *one-tailed* test
$\text{Prob}(x \geqq x_r) \geqq \alpha = \text{Prob}(x > x_{r-1})$ **(3**

– rules **(381)** and **(382)** are valid for *all* significance limits of *discrete* distributions tabulated in these *Tables*. Elsewhere, significance limits of discrete distributions may be found which must be exceeded in an *outward* direction if, for example, they are to satisfy the rule $P_l \leqq \alpha$. **(38**

– as a rule the *actual* significance probability P in *discrete* distributions is *smaller* than the *nominal* α, for small values of N often considerably smaller. With increasing values of N this difference decreases rapidly. (In example 13 with $\alpha = 0.10$ or 0.025, the corresponding values of P are 0.0547 or 0.0108. In this case the actual significance probability amounts to only about 50% of the nominal.) **(38**

The following definitions should also be noted:

The range between $x_l + 1$ and N or between zero and $x_r - 1$ is the *one-sided confidence interval.* **(385**

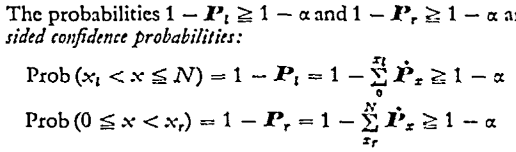


Fig. 4. One-sided confidence intervals for discrete distributions.

x_l or x_r is the *one-sided confidence limit* when the other limit lies at N or zero. **(386)**

The probabilities $1 - P_l \geqq 1 - \alpha$ and $1 - P_r \geqq 1 - \alpha$ are the *one-sided confidence probabilities:*

$$\text{Prob}(x_l < x \leqq N) = 1 - P_l = 1 - \sum_{0}^{x_l} \dot{P}_x \geqq 1 - \alpha \qquad (387)$$

$$\text{Prob}(0 \leqq x < x_r) = 1 - P_r = 1 - \sum_{x_r}^{N} \dot{P}_x \geqq 1 - \alpha \qquad (388)$$

From **(380)** and **(386)** it will be seen that significance limits and confidence intervals are determined mathematically according to the same principles. **(389)**

B. Two-sided significance limits

If a left and a right significance limit are determined jointly for a discrete distribution according to rules **(376)** and **(377)**, then for the two together $P_l + P_r \leqq 2\alpha$. **(390)**

In this case the following definitions apply:

2α is the *postulated* or *nominal two-sided significance probability*. **(391)**

$P_l + P_r$ is the *actual two-sided significance probability* [note also **(384)**], where $P_l = P_r$ in symmetrical distributions and $P_l \neq P_r$ in unsymmetrical distributions, although both satisfy rules **(376)** and **(377)** (cf. Fig. 5). **(392)**

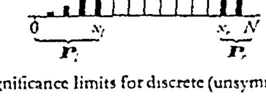


Fig. 5. Two-sided significance limits for discrete (unsymmetrical) distributions.

x_l and x_r t [illegible] limits (with [illegible] **(393)**

It should be noted that

hen x *attains or exceeds* (outwards) *one of the two* significance limits x_l or x_r, then in a *two-sided* test
$\text{Prob}(x \leq x_l) + \text{Prob}(x \geq x_r) \leq 2\alpha =$
$\text{Prob}(x < x_{l+1}) + \text{Prob}(x > x_{r-1})$ **(394)**

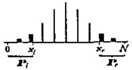


Fig 6 Two-sided significance limits for discrete (symmetrical) distributions

The following definitions should also be noted

The range between $x_l + 1$ and $x_r - 1$ is the two-sided confidence interval, or briefly *confidence interval* **(395)**

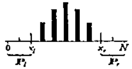


Fig 7 Two-sided confidence interval for discrete distributions

x_l and x_r are the two-sided confidence limits, or briefly *confidence limits*, whereby it should again be noted that significance limits and confidence intervals are determined mathematically according to the same principles **(396)**

The probability $1 - P_l - P_r \geq 1 - 2\alpha$ is the actual two-sided confidence probability, or briefly *confidence probability*

$$\text{Prob}(x_l < x < x_r) = 1 - P_l - P_r$$
$$= 1 - \sum_{0}^{x_l} P_x - \sum_{x_r}^{N} P_x \geq 1 - 2\alpha \qquad \textbf{(397)}$$

6. Continuous probability distribution

A comparison of Figures 1 and 8 reveals the similarity between discrete and continuous distributions When the distribution shown [illegible]

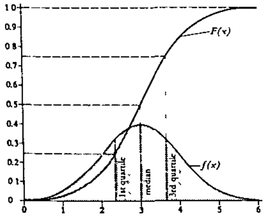


Fig 8 Abscissae x, ordinates probability density function $f(x)$ and probability $F(x)$

In probability distributions such as those of Figure 8, x is a *continuous* random variable [cf (343)], there is an infinite number of events x, so that

$$\text{Prob}(x = k) = 1/\infty = 0 \qquad \textbf{(398)}$$

and

$$\text{Prob}(x \leq k) = \text{Prob}(x < k) + \text{Prob}(x = k) = \text{Prob}(x < k) + 0$$

In practice therefore the following should be noted.

For *continuous* distributions (with an error of zero magnitude)
Prob $(x \leq k)$ can be written as Prob $(x < k)$
Prob $(x \geq k)$ can be written as Prob $(x > k)$ **(399)**

In discrete distributions the individual probability Prob $(x = k)$ can be read from $f(x)$ but this no longer applies in continuous distributions

In a continuous distribution, $f(x)$ is the *probability density function* at the point x. **(400)**

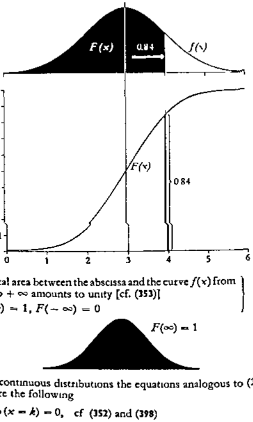
The cumulative probability distribution $F(x)$ has the same significance in continuous distributions, however, as in discrete distributions: it represents the probabilities of the events $x \leq k$ In contrast to the case with discrete distributions, the latter are equivalent to the events $x < k$ [cf. (399)] **(401)**

In discrete distributions, $F(x)$ is the *sum* of the individual probabilities [cf. (372)] In continuous distributions, $F(x)$ is an *integral*

$$F(x) = \int_{-\infty}^{x} f(x)\,dx$$

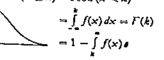
i e, $F(x)$ corresponds to the area between the abscissa and the curve $f(x)$ from $-\infty$ to x **(402)**

Fig 9



The total area between the abscissa and the curve $f(x)$ from $-\infty$ to $+\infty$ amounts to unity [cf. (353)]
$F(\infty) = 1, F(-\infty) = 0$ **(403)**

Fig 10



For continuous distributions the equations analogous to (370)–(375) are the following

$\text{Prob}(x = k) = 0$, cf (352) and (398)

$\text{Prob}(x \neq k) = 1$, cf (352) **(404)**

$$\text{Prob}(x \leq k) = \text{Prob}(x < k) \qquad \textbf{(405)}$$
$$= \int_{-\infty}^{k} f(x)\,dx = F(k) \qquad \text{(a)}$$
$$= 1 - \int_{k}^{\infty} f(x)\,dx \qquad \text{(b)}$$

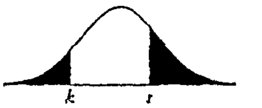
$$\text{Prob}(x \geq k) = \text{Prob}(x > k) \qquad \textbf{(406)}$$
$$= 1 - \int_{-\infty}^{k} f(x)\,dx = 1 - F(k) \qquad \text{(a)}$$
$$= \int_{k}^{\infty} f(x)\,dx \qquad \text{(b)}$$

$$\left.\begin{aligned}\text{Prob}\,(k \leqq x \leqq s) &= \int_{-\infty}^{s} f(x)\,dx - \int_{-\infty}^{k} f(x)\,dx \\ &= F(s) - F(k)\end{aligned}\right\} \quad (407a)$$

$$= 1 - \int_{-\infty}^{k} f(x)\,dx - \int_{s}^{\infty} f(x)\,dx \quad (b)$$

$$= \int_{k}^{s} f(x)\,dx \quad (c)$$

$$\left.\begin{aligned}\text{Prob}(x < k) + \text{Prob}(x > s) &= 1 - \int_{-\infty}^{s} f(x)\,dx + \int_{-\infty}^{k} f(x)\,dx \\ &= 1 - F(s) + F(k)\end{aligned}\right\} \quad (408a)$$



$$= \int_{-\infty}^{k} f(x)\,dx + \int_{s}^{\infty} f(x)\,dx \quad (b)$$

$$= 1 - \int_{k}^{s} f(x)\,dx \quad (c)$$

In equations **(405)**–**(408)**, comparison with **(399)** shows for example that Prob $(k \leqq x \leqq s)$ is the same as Prob $(k < x \leqq s)$, Prob $(k \leqq x < s)$ and Prob $(k < x < s)$.

The numerical values of the various integrals in **(405)**–**(408)** for the most important distributions will be found in the statistical tables on pages 28 onward. They will be discussed further under the headings of the individual distributions later in this chapter. In the examples below in which probabilities in the normal distribution are calculated, the abscissae x are designated deviations c. In the table on page 28, $F(c)$ values are tabulated on the right (deviation → integral), i.e., *the probabilities $F(c)$ for given deviations c.* On the left (integral → deviation) are deviations c for given probabilities, so that here the deviation c is a function of $F(c)$, known as the quantile c (cf. section 10E, page 160). Such a function is known as an *inverse function.* Tables of inverse functions are useful but not absolutely necessary. The values required can also be obtained from tables of basic functions by interpolation.

Example 14. The probabilities for $k = -1.65$ and $s = 1.96$ are calculated for the normal distribution using the form (a) of equations **(405)** to **(408)**.

The right-hand side of the table on page 28 gives $F(-1.65) = 0.04947$ and $F(1.96) = 0.97500$, so that

(405): Prob $(c \leqq -1.65) = 0.04947$

(406): Prob $(c \geqq -1.65) = 1 - 0.04947 = 0.95053$

(407): Prob $(-1.65 \leqq c \leqq 1.96) = 0.97500 - 0.04947 = 0.92553$

(408): Prob $(c \neq -1.65$ to $1.96) = 1 - 0.97500 + 0.04947 = 0.07447$

Example 15. Given the probabilities $F(c) = 0.001$ and 0.995 it is required to find the corresponding deviations c. The left-hand side of the table on page 28 gives $c = -3.0902$ and 2.5758. The corresponding values taken from the right-hand side without interpolation are 3.09 and 2.58.

Example 16

Confidence intervals* and significance limits
(Cf. also sections 8 and 9, pages 154–159)

A. One-sided significance limits

Given α, where $0 < \alpha \leqq 0.5$, determine x_l and x_r in such a way that

$$\text{Prob}\,(x < x_l) = \boldsymbol{P}_l = \int_{-\infty}^{x_l} f(x)\,dx = F(x_l) = \alpha \quad (409)$$

$$\left.\begin{aligned}\text{Prob}\,(x > x_r) = \boldsymbol{P}_r &= \int_{x_r}^{\infty} f(x)\,dx = 1 - \int_{-\infty}^{x_r} f(x)\,dx \\ &= 1 - F(x_r) = \alpha\end{aligned}\right\} \quad (410)$$

From **(410)** it follows that $F(x_r) = 1 - \alpha$ **(411)**

For the normal distribution, the table on page 28, left-hand side, gives for $\alpha = 0.025$, $x_l = -1.96$ and $x_r = 1.96$.

The definitions of the symbols α, $\boldsymbol{P}_l$, $\boldsymbol{P}_r$, x_l and x_r in **(409)** and **(410)** are the same as in *(378)*, *(379)* and *(380)*.

* Also known as 'tolerance intervals'. Cf. section 8, page 154.

It will be noted, however, that in contrast to discrete distributions [cf. **(384)**], the actual and nominal significance probabilities in continuous distributions are of the same magnitude. In continuous distributions therefore, the simple expression 'significance probability' is used, the symbols $\boldsymbol{P}$ and α becoming synonymous.

As in the case of discrete distributions it follows that:

If x *attains or exceeds* (to the left) the *left* (lower) significance limit x_l, then in a *one-tailed* test
Prob $(x \leqq x_l) \leqq \alpha =$ Prob $(x < x_l)$ (

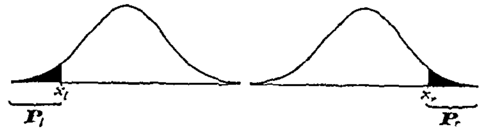


Fig. 11. One-sided significance limits for continuous distributions.

If x *attains or exceeds* (to the right) the *right* (upper) significance limit x_r, then in a *one-tailed* test
Prob $(x \geqq x_r) \leqq \alpha =$ Prob $(x > x_r)$ (4

The following definitions should also be noted:

The range between x_l and ∞ or between $-\infty$ and x_r is the *one-sided confidence interval.* (4

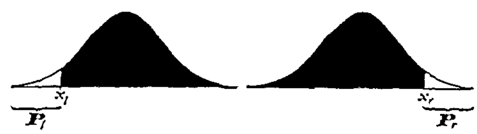


Fig. 12. One-sided confidence intervals for continuous distributions.

x_l and x_r are the *one-sided confidence limits* when the other limit lies at ∞ and $-\infty$ respectively. Again, significance limits and confidence intervals for continuous distributions are determined according to the same mathematical principles. (41

B. Two-sided significance limits

When a left and a right significance limit are jointly determined for a continuous distribution according to rules *(409)* and *(410)*, then for the two together $\boldsymbol{P}_l + \boldsymbol{P}_r = 2\boldsymbol{P} = 2\alpha$. (41

In this case

$2\boldsymbol{P} = 2\alpha$ is the *two-sided significance level.* (41

x_l and x_r together are the *two-sided* significance limits, or briefly the *significance limits.* (41

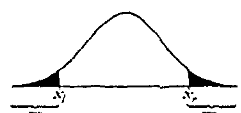


Fig. 13. Two-sided significance limits for continuous distributions.

It should be noted:

If x *attains or exceeds* (outwards) *one of the two* significance limits x_l or x_r, then in a *two-tailed* test
Prob $(x \leqq x_l)$ + Prob $(x \geqq x_r) \leqq 2\alpha =$
Prob $(x < x_l)$ + Prob $(x > x_r)$ (420

The following definitions should also be noted:

The range between x_l and x_r is the *two-sided* confidence interval, or briefly the *confidence interval.* (421)

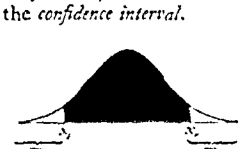


Fig. 14. Two-sided confidence interval for continuous distributions

x_l and x_r are the *two-sided* confidence limits (with symmetrical probability), or briefly the *confidence limits*. (422)

The probability $1 - 2P = 1 - 2\alpha$ is the two-sided confidence probability, or briefly the *confidence probability*: (423)

$$\text{Prob}\,(x_l \leq x \leq x_r) = 1 - 2P$$

$$= 1 - \int_{-\infty}^{x_l} f(x)\,dx - \int_{x_r}^{\infty} f(x)\,dx = \int_{x_l}^{x_r} f(x)\,dx$$

$$= \int_{-\infty}^{x_r} f(x)\,dx - \int_{-\infty}^{x_l} f(x)\,dx = F(x_r) - F(x_l) = 1 - 2\alpha$$

7. Estimates

The variables of a population are usually known but not always the type of distribution and rarely the parameters, so that the distribution or its parameters must be estimated on the basis of samples. Estimates can be calculated from a sample using the same rules as for calculating the corresponding parameter of the population. This method of estimating is frequently used but it is not the only one and does not always ...

unnecessary in practice since for the commonest cases a recognized estimating formula can be used.

7A. Expectation and bias

It is assumed that an estimate of some parameter P from a sample of size N is required.

Experience has shown that when a number of similar estimates are made from samples of the *same* size the mean of these estimates approaches closer and closer to a definite value – the *expected value* or *expectation* of the estimate – when the number of samples is increased toward infinity (cf. Fig. 15) (424)

This convergence, however, is not a convergence in the usual mathematical sense but a *convergence in probability* or *stochastic convergence*, i.e., '*the probability that ... converges toward unity or zero*' [cf. (427)]

When the expectation of an estimate is equal to the parameter, the estimate is said to be *unbiased*. When this is not the case, the estimate has *bias*. (425)

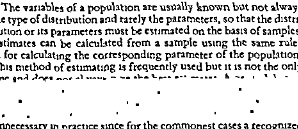
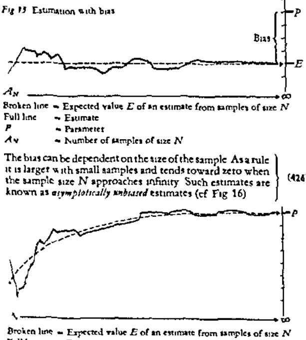


Fig 15 Estimation with bias

Broken line = Expected value E of an estimate from samples of size N
Full line = Estimate
P = Parameter
A_N = Number of samples of size N

The bias can be dependent on the size of the sample. As a rule it is larger with small samples and tends toward zero when the sample size N approaches infinity. Such estimates are known as *asymptotically unbiased* estimates (cf. Fig 16) (426)



Broken line = Expected value E of an estimate from samples of size N
Full line = Estimate
P = Parameter

Fig 16 Asymptotically unbiased estimation

* 'Higher' from the standpoint of the non mathematician

The bias described above is a mathematical one, that is, one herent in the estimation. If the magnitude of this 'internal' bi known, it can be eliminated by appropriate corrections*. An mate can also have a non-mathematical, 'external' bias, howe due to errors of measurement or judgment, to nonrandom lection of samples, or to both these causes. Such a bias is ...

7B. Consistency

As in (424), experience has shown that with increasing sample size, estimates also usually tend toward a definite value, the expected value in *infinitely large* samples:

If with increasing sample size N a parameter remains *constant*, then Prob (| estimate minus expectation | $< \varepsilon) \to 1$ ($\varepsilon > 0$), as the sample size $N \to \infty$ (a)

(a) is also valid for parameters that with increasing sample size N increase in proportion to N, N^2, etc. when the absolute value of the difference between estimate and expected value is divided by N, N^2, etc. (b)

(427) ... 427 ...

7C. Efficiency

... reader is referred to the original publications.

Here the *most efficient estimate* is defined as that unbiased estimate of a parameter with variance equal to the lower bound of RAO-CRAMÉR. This will be assigned an efficiency of 100%.

Estimates fulfilling condition (428) for ...

Asymptotically most efficient estimates of (429) are suitable for χ^2 tests, others not.

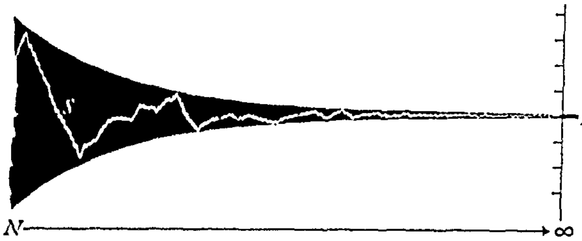
(430) ...

As a rule, the standard deviation of an estimate decreases either absolutely or relatively (to the magnitude of the estimate) as sample size increases (cf. Fig 17).

If a parameter remains *constant* with increasing sample size, the standard deviation of its estimate shows stochastic convergence toward zero of the order of $1/\sqrt{N}$ with increasing sample size N (a)

* Corrections are not always possible when N is finite

(a) is also valid for parameters that with increasing sample size N *increase* in proportion to N, N^2, etc. when the parameter, the estimate and its standard deviation are divided by N, N^2, etc. (b) (432)



■ Standard deviation
S Estimate
P Parameter

Fig. 17

If the efficiency of the estimate A is 100%, that of the estimate B for the same parameter 75%, then the sample size when using method B must be 100/75 times larger (⅓ as large again) than when using method A if the same degree of precision is to be obtained [provided that **(432)** applies]. **(433)**

Thus by increasing the size of the sample a less efficient estimate can be given the same precision as a more efficient one,

or conversely, for a given degree of precision the sample size can be smaller when a more efficient method of estimation is used (cf. Fig. 18). **(434)**

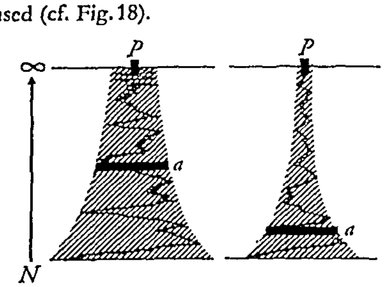


Fig. 18. *a* = precision of the estimate.

The question arises of which method to use in estimating a parameter when several formulae are available: that which yields the most efficient estimate but is more complicated, or a simpler but less efficient method? Theoretically, only the most efficient method should be used; in practice, however, the niceties of mathematical usage must be tempered by other considerations.

The most efficient of the known estimates of a parameter should be used **(435)**

- when tests are expensive in comparison with simple counting [cf. **(434)**],
- when the tests cannot be repeated,
- when χ^2 tests are planned,
- when the result must be as exact and informative as possible,
- when the most efficient estimate has been used in similar studies by other investigators (thus offering the possibility of comparisons and significance tests).

Where none of the reasons given in **(435)** apply, a less efficient but rapid method of estimating should be used **(436)**

- when simple counting is more costly than the tests [cf. **(434)**],
- when the precision of the method suffices for the purpose in mind,
- when the object is simply a rapid preliminary check of the results,
- when the investigations are of a routine nature,
- when it is necessary to check more efficient estimates in the calculation of which there is a high possibility of error.

7D. Sufficient estimates

An estimate or combination of estimates that in any given case yields *all the information* it is possible to obtain is known as a *sufficient estimate.* (4:

Information may be imagined (more or less) as the reciprocal of the variance. (4:

In conclusion it should be noted that as in the case of bias, t variance of an estimate is dependent on the experimental conditio and can be reduced by suitable planning of the investigation.

The designations 'consistent', 'efficient' and 'sufficient' are due R. A. Fisher. However, Fisher reserves the term 'efficient' for tho estimates described here as suitable for χ^2 tests [cf. **(430)** and **(431**

8. Confidence limits and tolerance limits

8A. Confidence limits for continuous and discrete distributio

In this subsection it is assumed that the reader is familiar wi examples 13 and 16, pages 150 and 152.

The estimation of a parameter alone does not yield a great de of information. In a continuous distribution, for example, as **(39** shows, the probability that the estimate [x in **(398)**] and paramet [k in **(398)**] agree is equal to zero. More information is provided b calculating from the sample the two values x_l and x_r that with a *hi probability* enclose the parameter between them. Such limits a known as *confidence limits.* The associated terminology and math matical definitions are given in examples 13 and 16 (pages 150 an 152).

The confidence limits used here are characterized as follows:

They are identical with the confidence limits of J. Neyman[8]. **(439**

The parameter to which they relate is a *constant.* **(440**

They are *estimates* and therefore *random variables.* Moreover, the *position of the limits* as well as the *width of the confidence interval* is a random variable (cf. Fig. 19). **(441**

Fig. 19. 95% confidence intervals for the parameter p of a binomially distributed population, calculated from 20 samples of size 40.

For a given sample size, *more efficient* estimates result in a *narrower* confidence interval than less efficient ones. **(442)**

In analogy with **(432)**, the confidence interval becomes absolutely or relatively (to the magnitude of the estimate) narrower with increasing sample size.

(443)

When a parameter remains *constant* with increasing sample size N, the confidence limits show stochastic convergence of the order of $1/\sqrt{N}$ toward the parameter and the width of the confidence interval shows stochastic convergence toward zero (cf. Fig. 20). (a)

When the parameter is divided by N, N^2, etc. and its confidence limits by N, N^2, etc., (a) is also valid for parameters that with increasing sample size N *increase* in proportion to N, N^2, etc. (b)

(444)

Confidence limits are to be interpreted as follows [see also **(456)**]: When very many (infinitely many) samples *of the same size* are taken *from the same stable population* and the confidence limits calculated for each, then these limits (*one-sided confidence intervals*)

- will enclose the true value of the parameter on the average in $\gtrsim 100(1-\alpha)\%$ of cases* (a)

or (an equally valid interpretation)

- will *not* enclose the true value of the parameter on the average in $\lesssim 100\alpha\%$ of cases* (b)

* The 'greater than' and 'smaller than' signs apply to discrete distributions, the 'equals' sign to continuous distributions.

sided confidence intervals)

ll enclose the true value of the parameter on the age in $\geq 100(1-2\alpha)\%$ of cases* (c) (444)

in equally valid interpretation)

(d)

parameter

a rule, the confidence probability 0 95 (more rarely)) is used in medical and biological studies, i e , α (one-sided intervals) or 2α (two-sided intervals) is equal to 0 05 more rarely 0 01) (445)

Formulae for the calculation of confidence intervals for various

Fiducial limits. This concept, introduced by R A Fisher, strictly speaking has a sense different to that of the *confidence limits* of Neyman *Fiducial limits* can be precisely determined only for certain continuous distributions. For discrete distributions they can be determined approximately, but then only when the sample size is large *Confidence limits* are not subject to these limitations and their use is therefore preferred here

3. Tolerance limits for continuous distributions

Limits for a percentage of a population are known as tolerance limits (446)

The percentage of the population is expressed as $100\beta_p\%$, the confidence probabilities associated with tolerance limits as β_t (447)

(441) and (442) are also valid for tolerance limits. (448)

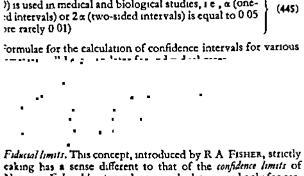


Fig 20 Convergence of confidence and tolerance limits

In analogy with (443), tolerance limits also converge stochastically with increasing sample size, ***but not toward one but toward two*** limiting parameters, namely those corresponding to the quantiles of the population between which lies the percentage of the population to which the tolerance limits relate The tolerance interval between these limits thus tends ***not toward zero*** but toward a ***positive whole number*** (cf Fig 20) (449)

Like confidence limits, tolerance limits can be one- or two-sided The following statements refer to two-sided tolerance limits in which

$$\beta_p = 1 - 2\alpha, \text{ and } \alpha\,(\text{left}) = \alpha\,(\text{right}) = \int_{-\infty}^{x_l} f(x)\,dx = \int_{x_r}^{\infty} f(x)\,dx$$

Tolerance limits with confidence probability β_t must be distinguished from those without They are interpreted as follows [note also (456)]

Sample tolerance limits without confidence probability. When very many (infinitely many) samples of the *same size* are taken from the *same stable population* and the tolerance limits calculated each time, then these limits

– will enclose *on the average* $100\beta_p\%$ of the population (a)

or (an equally valid interpretation)

– will *not* enclose on the average $100(1-\beta_p)\%$ of the population, whereby on the average $100\alpha\%$ of the population will lie *below* the left (lower) limit and $100\alpha\%$ *above* the right (upper) limit (b) (450)

Sample tolerance limits with confidence probability β_t When very many (infinitely many) samples of the *same size* are taken from the *same stable population* and the tolerance limits calculated each time, then these limits will include *at least* $100\beta_p\%$ of the population in an average of $100\beta_t\%$ of cases (451)

(452)

of a sample and a later single observation[9].

Tolerance intervals *with* confidence probability [interpretation (451)] are wider than those *without*, as would be expected With increasing sample size, however, both intervals converge toward the limiting interval of (499) (453)

present these have rarely been calculated precisely according to the rules for tolerance limits* However, with the aid of the tables given in this book, their exact calculation will involve additional calculation only in a minimum number of cases

Normal ranges should therefore be determined in accordance with the rules for tolerance limits, and

– in general, as tolerance intervals *without* confidence probability [interpretation (450)] for $100\beta_p\% = 95\%$ of the population [cf (452)] (a)

– in special cases (usually industrial, where for example the wastage must be kept as low as possible), as tolerance intervals *with* confidence probability β_t [interpretation (451)] (b) (454)

In the above text the word 'normal' has been used – in 'normally distributed' and 'normal range' – in two different senses

(455)

8C. Distribution-free confidence and tolerance limits

(Cf also section 10F, page 161)

Statements (444), (450) and (451) are correct only when the sample in fact originates from the population for whose parameter or percentage the limits were calculated. The formulae for calculating these limits are specific for the individual types of population (456)

If the type of distribution of a population is unknown, as is often the case, it is pointless – particularly with *small* samples – to calculate confidence and tolerance limits on the basis of *assumptions* concerning the distribution that are not justified by experience, the experimental conditions, and so on

* The 'greater than' and 'smaller than' signs apply to discrete distributions, the 'equals' sign to continuous distributions

* With large samples this is in any case pointless

In such cases the so-called *distribution-free* confidence and tolerance limits are used, provided that these are available for the case concerned. Statements (444), (450) and (451) are then valid *without any stipulation as to the distribution* of the population*, i.e., they are valid for *all* populations with the sole provision that these are *continuous*. (457)

Distribution-free confidence and tolerance limits are *wider* than those calculated for populations of a specific type. This is understandable in view of the fact that they must satisfy (444), (450) and (451) for populations of widely differing kinds.

Distribution-free confidence limits for quantiles (median, quartile, percentile, etc.) of small samples (up to $N = 100$) of continuous populations can be read off *without* calculation from the tables on pages 104 et seq. An introduction to the calculation of distribution-free confidence and tolerance limits will be found, together with formulae, in sections 10F (page 161) and 20F (page 186).

The table of distribution-free tolerance limits on page 128 can be used to solve problems of the following type without the need of calculation: At the start of a series of tests it is often necessary to decide the size of the sample to be taken *when it is impossible to know the form of the population distribution*. On the one hand the sample must be large enough to be reasonably representative of the population, on the other hand not unnecessarily large and wasteful. The answer is provided by distribution-free tolerance limits and for most purposes these can be read off directly from the table mentioned. For example, if the two extreme values of the sample are to include 90% of the population with the high probability of 0.999, then the table gives a sample size of 88. In other words, if a sample of size 88 is taken, then with a probability of 0.999, 90% of the population will lie between the 1st and 88th values of the sample.

9. Statistical significance tests

9A. Introduction

With a 'true' die the probability of throwing the number 1, 2, ..., 6 is by definition exactly 1/6, and the probability of throwing an even number is exactly ½. In accordance with (331), the probability ½ is a parameter of the population of events 'even number' and 'uneven number' produced by throwing the die.

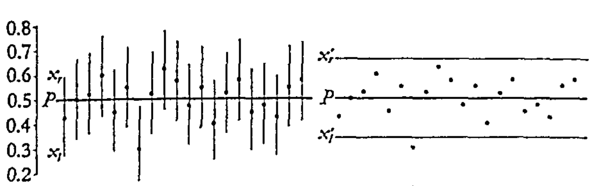


Fig. 21. 95% confidence limits (left) and corresponding 5% significance limits (right) for a given sample size (cf. legend of Fig. 19). The points are estimates p of the probability $\mathfrak{p} = ½$ (shown here as the parameter P).

Such a die can be used to check statement (444d). 20 samples of 40 throws each are made and in each sample the uneven numbers thrown used to determine the 95% confidence limits given in Figure 21 (left) for the parameter ½. In accordance with (444d), one of the 20 confidence intervals does not include the parameter (note arrow).

Supposing now that these confidence limits had been obtained not with samples consisting of *twenty throws of a known die* but with separate samples from *each of twenty unknown dice*. The suspicion would immediately arise that 'something was wrong' with that die for which the confidence interval did not include the parameter ½. Only one sample has been thrown with this die, and in this first solitary sample a rare event occurs that according to (444d) should only occur in the long run in 5% of cases**. The suspected die is therefore declared to be loaded, but with the reservation that this assertion may err with a significance probability of 0.05.

This is the principle on which, mutatis mutandis, all statistical tests are based.

* Hence the expression 'distribution-free'.

** Further consideration will show that such an occurrence is possible, although with a much lower probability, since (444d) gives no indication *when* a rare event has to occur in a series of tests. *With random events no such forecast can be made when the tests are independent.*

9B. Significance limits

The example given above demonstrates that signific can be performed with the aid of confidence limits:

In a significance test based on *confidence or tolerance limit* 1 or 2 *randomly variable limiting values* are compared with known or hypothetical *fixed parameter value* (cf. Fig. 21 left).

Many significance tests are performed with the aid c cance limits:

In a significance test based on *significance limits* in the usua sense, 1 or 2 *constant limiting values* are compared with *randomly variable test statistic* (cf. Fig. 21, right).

It is *immaterial* whether significance tests are made on the basis of confidence and tolerance limits or on the basis of significance limits in the usual sense: the result is the same (cf. Fig. 21, left and right). With both methods it is valid to deduce a significant difference [cf. (381), (382), (394), (413), (414) and (420)] *when the test statistic lies at or outside the limits*.

Confidence limits, tolerance limits and significance limits are intimately bound up with one another:

– either they differ from one another merely symbolically and are numerically identical (a)

– or they differ in respect of formula and numerical value, with the formulae mutually interconvertible. (b)

Example 17 [of (461 a)]. In the binomial distribution

$\mathfrak{p}_l < p < \mathfrak{p}_r$ are significance limits for p
$p_l < \mathfrak{p} < p_r$ are confidence limits for $\mathfrak{p}$

where $\mathfrak{p}$ are constants and p random variables. When then $\mathfrak{p}_l = p_l$ and $\mathfrak{p}_r = p_r$ (for the same sample size).

Example 18 [of (461 b)]. $\bar{x}$ is the mean, $s_{\bar{x}}$ the estimated st deviation of the mean of a sample from a normally dist population. μ_1 is the mean of the hypothetical populatior significance limit (corresponding to the sample size and significance probability) of the Student distribution (see 12A, page 166). Then

$\bar{x} - t s_{\bar{x}} < \mu_1 < \bar{x} + t s_{\bar{x}}$ are confidence limits for μ

$-t s_{\bar{x}} < \bar{x} - \mu_1 < +t s_{\bar{x}}$ are neither confidence lim significance limits in the sense (like the test statist limits are random variabl

$-t < \dfrac{\bar{x} - \mu_1}{s_{\bar{x}}} < +t$ are significance limits for $\dfrac{\bar{x} - \mu_1}{s_{\bar{x}}}$

All three formulae are suitable for testing the null hyp $\mu_0 = \mu_1$ [see (466)]. This is done by replacing μ_1 by the hyp cal comparison parameter μ_0 and noting the position of the with regard to the limits. The simplest formula (for beginn the first, the second allows the quickest calculation, while th is that most commonly used.

When the simple term 'limits' is used here in connectior significance tests [cf. (460) and (461) and their examples], then limits are meant which conform with rules (376) and (377) o and (410), depending on the population under consideratior

All limits suitable for significance tests converge absolutely or relatively with increasing sample size or with increasing numbers of samples of the same size [when (432) holds]. The statements in (443) and (449) concerning confidence and tolerance limits are valid for all such limits.

It follows from (462) that:

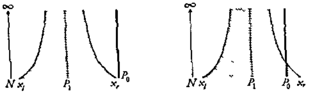
With increasing sample size, any difference existing can be demonstrated more and more significantly. (a)

With increasing sample size, smaller and smaller differences can be demonstrated for any given significance probability. (b)

When there is a real difference – shown by small samples to be significant – between a real and a hypothetical population, then with increasing sample size the assumption that the real population *differs* from the hypothetical will be *confirmed* (usually) with increasing significance (cf Fig 22a). (c)

When there is a real difference that *cannot* be shown … (d) (463)

When there is in fact *no* difference between a real and a hypothetical population, then it *may* be possible to demonstrate this with some certainty with very large samples (with complete certainty only with infinitely large samples) (e)



a [cf (463c)]   b [cf (463d)]

Fig 22 a and b P_0 is the hypothetical parameter, P_1 that to be tested, x_l and x_r are the confidence limits of P_1 converging with increasing sample size

9C. Significance tests

General

All statistical tests are based on the fundamental principle of comparing an *unknown population* from which the sample originates with a *known or hypothetical population* (464)

All statistical tests confirm with precise significance probability only differences between the populations compared, *not* their identity [cf also (463)] (465)

The hypothesis H_0 that 2 populations are identical is known as the *null hypothesis* As implied in (465), it is usually postulated in order to be *disproved* (466)

The expression null hypothesis is derived from the postulated identity of the population P_1 from which the sample originates with the hypothetical population P_0, whence $P_1 = P_0$, so that $P_1 - P_0 = 0$ (null)

When a statistical test* 'demonstrates' a difference between … (467)

difference where none exists, is α or 2α

The probability of making an *error of the second kind*, i e, of accepting the null hypothesis when it is untrue, in other words of not determining a difference where one exists, is β The probabilities α and β are closely related as α decreases β increases, and vice versa (note, however, that β is *not* $1 - \alpha$ or $1 - 2\alpha$, the reader is referred to more advanced statistical treatises for a detailed discussion of this relationship) (468)

With increasing sample size it can be arranged that the probabilities of making an error of the first or second kind both decrease (469)

Remarks on (467) and (468) When it is important to avoid making an error of the first kind, i e, when it is necessary to be quite certain that a difference exists before accepting it, then a small value of α or 2α is chosen, say between 10^{-3} and 10^{-6} or less, according to the risk it is permissible to take

* In the subsequent text the word 'test' is used to mean 'statistical test'

On the other hand, in a series of experiments designed to …

Power of a test

The probability $1 - \beta$, i e, the probability of disclosing a difference when one actually exists, is known as the *power* of a test. (470)

From (469) it follows that the power of a test can be increased (usually) by increasing the sample size (471)

… (472)

Remarks on (472) A useful analogy is that of the police searching for a criminal the more that is known about him, the more effective (more powerful) will the search (the test) be

The *relative* power of different tests having the same object can *only* be decided by their use on *known* populations (473)

Remarks on (473) The relative power of a test (previously calculated on the basis of some specific situation) is thus useless as a …

Interpretations [cf also (476)]

When the purpose of a series of experiments is to demonstrate the *identity* of two populations, then the *failure* of an appropriate test to establish a significant difference justifies acceptance of the null hypothesis as long as it is not controverted by further experimentation (474)

Remarks on (474) It is a common mistake to consider the identity of two populations as proven when no significant difference can be shown [cf also (463d and e) and Fig 22b]

When the purpose of a series of experiments is to demonstrate a *difference* between two … (475)

Remarks on (475) The interpretation 'There is *no* difference' would be incorrect [cf also (463d and e) and Fig 22b].

One-tailed and two-tailed tests

When from previous experience or on theoretical grounds the …

* When α or 2α serves as a criterion of *decision* (rejection or acceptance of the null hypothesis), then the decision as to its magnitude must be made *independently* of the sample being tested, that is to say, if the investigator is in direct contact with the sample then *before* it is taken, if he is not in direct contact with it then *before* starting the statistical analysis

Interpretation of one-tailed tests*

Required significance	Test statistic: Hypothetical	Test statistic: Test	Interpretation and (in brackets) significance: One-tailed	Interpretation and (in brackets) significance: Two-tailed
α	$x < x_l$	$x \leqq x_l$	$x < x_l\ (\leqq \alpha)$	None
		$x > x_l$	(475)	
α	$x > x_r$	$x \geqq x_r$	$x > x_r\ (\leqq \alpha)$	
		$x < x_r$	(475)	

Interpretation of two-tailed tests*

2α	Uncertain	$x \leqq x_l$	$x < x_l\ (\leqq 2\alpha)$	Not equal (2α)
		$x \geqq x_r$	$x > x_r\ (\leqq 2\alpha)$	
		$x_l < x < x_r$	(475) or (474)	

(476)

In general, however, particularly at the start of an investigation, there will be considerable doubt as to which of the populations is the smaller and which the larger, even if they can be distinguished at all. In this case a *two-tailed test* should be made. If no definite choice between a one- or a two-tailed test was made before sampling then no alternative to the latter test remains. The significance probability is 2α, conventionally 0.05 or 0.01**, i.e., $\alpha = 0.025$ or 0.005 [cf. remarks on **(467)** and **(468)**]. Note that even when the two-tailed test is interpreted as a one-tailed test, the significance probability of this interpretation is still 2α.

It should also be noted that the interpretation referred to here relates to the *test statistic*. The *real* interpretation based on this may be different. **(476)** is merely a summarized form of **(381)**, **(382)**, **(392)**, **(413)**, **(414)**, **(420)**, **(474)** and **(475)**.

Conditions requiring fulfilment

It follows from **(472)** that in a situation in which several tests are available the one chosen will usually be that with the greatest power. According to **(473)**, however, the choice is only possible when the form of the populations to be compared is known. The form may be known from *previous experience* or from *theoretical considerations* (game of chance, central limit theorem), or may be deduced from the sample itself when this is very large. When the sample is small, however, particularly in complex biological, medical or psychological studies, the form of the population is often unknown. In such cases, *assumptions* concerning the form are only too often made simply for the purpose of being able to apply a 'more powerful' test [which in actual fact it may not be; cf. **(473)**]. For the following reasons this should be avoided as far as possible:

In regard to the *reliability* of a statistical test result, it is wiser to risk losing a little of the information contained in the sample and to use a test contingent on fewer conditions and involving fewer assumptions or even none at all. A possibly more powerful test would require assumptions to be made that may result in illusory information not contained in the sample. **(477)**

When the conditions on which a test is based are not, or only partly, fulfilled, then the probabilities of making an error of the first or second kind are modified in a manner difficult to estimate. The one certainty is that the probabilities *valid* when the conditions are *fulfilled* are *no longer precise* or may be misleading when the conditions are not, or only partly, fulfilled. **(478)**

First of all therefore, in situations where several tests are available, care should be taken to choose a test in which (if possible) all the conditions it involves are *actually* fulfilled in the case under consideration. **(479)**

Situations are often encountered in which a choice according to **(479)** is impossible because in none of the available tests (sometimes there is only one) can all the conditions be fulfilled. In such a case the test result should be interpreted with a degree of *caution* depending on the effects the non-fulfillment of the conditions could have in the case concerned. It is advisable to *specify the conditions which cannot be fulfilled*, for example as follows: 'On condition that both samples originate from the same normally distributed population, there exists...' **(480)**

It has already been stressed that the form of the population has an important bearing on the validity of many tests. In **(477)**–**(480)**, however, conditions for tests are mentioned in a quite general sense. The number of conditions and their 'severity' varies from test to test: obviously as many as possible should be fulfilled and not only those concerned with the form of the population. One condition which is fundamental to *all* tests is the following:

All statistical tests require that the samples should be *random* samples, that is to say, that they should be drawn by means of an operation fundamentally similar to that described in section 1, page 146. **(481)**

While this stipulation **(481)** is probably the most important condition in the whole field of statistics it is a very difficult one to fulfil completely in practice, especially in medical and biological studies. When an investigation has reached the stage of statistical testing, any nonrandom samples can probably be discarded provided that testing for nonrandomness is possible in the case concerned. Although this guards against making an erroneous decision, both time and money will have been wasted. For this reason it is advisable – *before* starting the investigation – to take all possible measures to ensure (maximum) randomness of sampling.

When as in **(479)** there are several permissible tests, no generally valid rules can be laid down as to how the choice should be made. Usually the first tests adopted will be those involving the least amount of calculation. If these do not give the postulated level of significance, they will be followed by more powerful tests from among those permissible. Such a procedure is in order* provided that it does not result in the mistake of assuming that a significance is doubly (or more than doubly) guaranteed when two (or more) tests give a significant result. The reason for this is that between many tests there exist correlations not always apparent even to the statistician: to some extent they test in the same manner but with different degrees of acuity. An analogy is provided by the viewing of an object under the microscope at three different magnifications: one is unlikely to fall into the error of assuming that its existence is triply confirmed. Similar but less easily recognizable relationships hold for tests between which there are correlations.

Example 19. Given the sample (in chronological order)

1 hour
– 0.7 hour
0.5 hour   Mean $\bar{x}$ = 1.07 hour
1.1 hour   Median M = 1.1 hour
3 hours
1.2 hour
1.4 hour

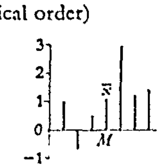


Fig. 23

representing the differences between pairs of observations on the same subject, for example after the administration of two barbiturates. The question is whether these differences differ significantly from zero ($2\alpha = 0.05$).

In such a case the following 7 tests are available (these are all given in the statistical tables preceding this chapter with the exception of the maximum test, for which the significance limits can be memorized):

Test	Stipulation regarding form of population	Calculation involved
1 Student (t-test).....	Normally distributed	Among these tests the most
2 LORD............	Normally distributed	About ¼ of that in 1
3 Midrange (WALSH) .	Normally distributed	Less than in 2
4 WALSH	Symmetrical	About the same as in 2
5 Sign.............	None	None
6 Maximum (WALTER)	None	Arrangement only
7 WILCOXON	None	About the same as in 2

If it is known that the sample is from a normally distributed population, then *all* of these tests can be tried. In this case the

* For discrete distributions $x < x_l + 1$ and $x > x_r - 1$ are used.
** See page 157, right-hand column, footnote.

* The editors know of no precise indications in this respect.

st powerful is the Student test, followed by the LORD and midge tests, which are only slightly less powerful with samples of small size. For normally distributed populations the WILCOXON is also little inferior to the Student test.

f nothing is known of the form of the population, then tests 5, nd 7 must be used, in accordance with (479). In the event of use of all these only the interpretation given in (475) remains. In the above example the tests yield the following significances:

Test	Significance
Student	$0.025 < 2\alpha < 0.05$
LORD	$0.05 < 2\alpha < 0.1$
Midrange	$0.05 < 2\alpha < 0.1$
WALSH	–
Sign	$0.05 < 2\alpha$
Maximum	$0.05 < 2\alpha < 0.1$
WILCOXON	$2\alpha < 0.05$

The Student, midrange and WILCOXON tests yield the desired gnificance while the others more or less fail. This reflects the fact hat when two samples are to be tested with respect to a difference in location between their populations, then as a rule for normally

[illegible]

estigation by further experiment

Common sense in statistical testing

Division of the sample values in example 19 above by 10 leaves the significances resulting from the tests unchanged. This would result in a statistically 'guaranteed' difference in the action of the [illegible]

[illegible]

10. Parameters

Means, variances and quantiles are dealt with only in a general manner in this section. Special formulae for calculating means and variances of various distributions are given in the sections dealing with these distributions.

10A. Mean and variance of the population

[illegible] (482)

The square root of the variance is known as the *standard deviation* (σ) (483)

The variance and standard deviation *of the mean* are expressed respectively by σ^2/N and $\sigma/\sqrt{N}$ and given the symbols $\sigma_{\bar{x}}^2$ and $\sigma_{\bar{x}}$ (484)

The quotient σ/μ is known as the coefficient of variance V. It is therefore the standard deviation with the mean expressed as unity. V has meaning only for *positive* values of x (485)

The standard deviation is a measure of the variance. The smaller it is, the steeper the curve of the distribution, the larger it is, the flatter the curve (cf. Fig. 25). This relationship is the basis of the CHEBYSHEF Inequality.

$$\left.\begin{array}{l} \mathrm{Prob}(|x-\mu| \geqq k\sigma) \leqq 1/k^2 = 2\alpha \quad (k>1) \\ \text{For } 1/k^2 = 2\alpha = 0.05 \text{ and } 0.01,\ k \text{ is respectively } \sim 4.5 \\ \text{and } 10. \text{ This inequality is valid for } any \text{ population} \end{array}\right\} \quad (486)$$

10B. Transformations

If the variable x is subject to a constant increment a, then

$$X = x \pm a$$

so that

$$\left.\begin{array}{l} \mu_X = \mu_x \pm a \\ \sigma_X^2 = \sigma_x^2 \end{array}\right\} \text{(a)} \quad (487)$$

The inverse transformation is

$$\left.\begin{array}{l} \mu_x = \mu_X \mp a \\ \sigma_x^2 = \sigma_X^2 \end{array}\right\} \text{(b)}$$

The variance is *unaffected* by a lateral displacement, i.e., it is translation-invariant.

If the variable x is increased or decreased by a constant factor a, then

$$X = a x$$

so that

$$\left.\begin{array}{l} \mu_X = a\,\mu_x \\ \sigma_X^2 = a^2\sigma_x^2 \end{array}\right\} \text{(a)} \quad (488)$$

The inverse transformation is

$$\left.\begin{array}{l} \mu_x = \mu_X/a \\ \sigma_x^2 = \sigma_X^2/a^2 \end{array}\right\} \text{(b)}$$

(487) and (488) are also valid for the estimates $\bar{x}$, $\bar{X}$ and s_x, s_X of μ_x, μ_X and σ_x, σ_X, the calculation of which they often render easier.

Example 20

(*a*) Given

x = 145 145.5 147 147.3 Then with $X = x - 145$
X = 0 0.5 2 2.3 from which values $\bar{X}$ and s_X^2 are calculated, when

$\bar{x} = \bar{X} + 145 = 1.2 + 145 = 146.2$ [$\bar{X}$ from (491)]
$s_x^2 = s_X^2 = 1.26$ [s_X^2 from (493)]

(*b*) Given

x = 0.00325 0.00160 0.00320 Then with $X = 10^5 x$
X = 325 160 320 from which values $\bar{X}$ and s_X^2 are calculated, when

$\bar{x} = \bar{X}/10^5 = 268.3 \times 10^{-5} = 0.002683$ [$\bar{X}$ from (491)]
$s_x^2 = s_X^2/10^{10} = 8808.3 \times 10^{-10} = 8.8083 \times 10^{-7}$ [s_X^2 from (493)]

A variable x whose distribution has
mean $= 0$
and variance $= 1$
is known as a *standardized* variable, or variable in *standard measure* (489)

If a variable x has the mean μ and the variance σ^2, then the variable

$$X = \frac{x-\mu}{\sigma} \quad \text{(a)}$$

is in standard measure. (490)

From the standardized variable X the original variable

$$x = \sigma X + \mu \quad \text{(b)}$$

is obtained.

(489) and (490) are in common use in statistics.

10C. Estimates of μ and σ based on ungrouped samples

The *most efficient, unbiased* estimate of the mean μ based on a sample from a normal population with the values $x_1, x_2, \ldots, x_N$ is

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_N}{N} = \frac{\Sigma x}{N} \qquad (491)$$

($\bar{x}$ is read as 'x bar'.)

The *most efficient, unbiased* estimate s^2 of the variance σ^2 is

(*a*) when μ is known

$$s^2 = \frac{\Sigma (x - \mu)^2}{N} = \frac{S'_x}{N}; \text{ for } S'_x \text{ see (493a and b)} \qquad \text{(a)}$$

(*b*) when μ is unknown

$$s^2 = \frac{\Sigma (x - \bar{x})^2}{N-1} = \frac{S_x}{N-1}; \text{ for } S_x \text{ see (493)} \qquad \text{(b)} \qquad (492)$$

The calculation of S_x (this symbol should be noted) is facilitated by the use of the following sums:

$$\left.\begin{aligned} S_x &= \Sigma (x - \bar{x})^2 \\ &= \Sigma x^2 - N\bar{x}^2 \end{aligned}\right\} \text{for } S'_x \text{ write } \mu \text{ instead of } \bar{x} \qquad \begin{matrix}\text{(a)}\\ \text{(b)}\end{matrix}$$

$$\begin{aligned} &= \Sigma x^2 - \bar{x}\Sigma x && \text{(c)} \\ &= \Sigma x^2 - (\Sigma x)^2/N && \text{(d)} \\ &[= s^2(N-1)] && \text{(e)} \end{aligned} \qquad (493)$$

The most efficient *asymptotically* unbiased estimate of σ is s. In practice the bias of s can usually be neglected. Correction factors for eliminating this bias in samples from normally distributed populations are given on page 47. (494)

The most efficient unbiased estimate of $\sigma^2_{\bar{x}}$ is $s^2_{\bar{x}} = s^2/N$, the most efficient asymptotically unbiased estimate of $\sigma_{\bar{x}}$ is $s_{\bar{x}} = s/\sqrt{N}$. Cf. also (494). (495)

Other estimates of σ will be dealt with later.

Example 21 [of (491)–(495)]. Given the sample of example 19, page 158,

then according to formula (491) $\bar{x} = 7.5/7 = 1.0714$

(493) $S_x = 15.35 - 8.0357 \approx 7.3143$

(492) $s^2 = 7.3143/6 = 1.2190$

(494) $s = \sqrt{1.2190} = 1.1041$

(495) $s_{\bar{x}} = 1.1041/\sqrt{7} = 0.4173$

The results should finally be rounded off to a few decimal places in order not to imply an accuracy the estimates do not possess.

10D. Estimates of μ and σ^2 based on grouped samples

Given the classes $x_1, x_2, \ldots, x_n$ with the same class width for all classes $d = x_{i+1} - x_i$ and the frequencies $f_1, f_2, \ldots, f_n$ $(N = \Sigma f_i)$, a provisional mean $\bar{x}'$ is chosen falling in one class. The classes are now numbered. $\bar{x}'$ receives the number $z = 0$, the classes downwards receive the numbers $z = -1, -2, \ldots$, the classes upwards the numbers $z = 1, 2, \ldots$

Classes ... $(\bar{x}' - 2)$ $(\bar{x}' - 1)$ $\bar{x}'$ $(\bar{x}' + 1)$ $(\bar{x}' + 2)$ ...

z ... -2 -1 0 1 2 ...

Then

$$\bar{x} = \bar{x}' + d\,\frac{\Sigma f z}{N} \qquad (496)$$

$$s^2 = \frac{d^2}{N-1}\left(\Sigma (f z^2) - \frac{(\Sigma f z)^2}{N}\right) \qquad (497)$$

SHEPPARD's *correction*

In the grouping of the individual values into classes a small error arises as a result of the random choice of the individual values. This introduces a small error into the estimate of the variance that can be corrected by subtraction of $k = 0.08\dot{3}$ (i.e., of 1/12) from the variance estimated in class units. This correction (SHEPPARD's correction) can be dispensed with in the testing of differences for significance but is otherwise to be recommended.

$$\text{SHEPPARD's correction: } s^2_{\text{corr.}} = s^2 - \frac{d^2}{12} \qquad (498)$$

Example 22. Diameter of erythrocytes. Class width $d = 0.4$

Class	Frequency f	Deviation z	Frequency × deviation fz	Frequ… × sq… of devi… $fz^2 = \ldots$
5.6	5	−4	−20	8…
6.0	78	−3	−234	70…
6.4	144	−2	−288	57…
6.8	479	−1	−479	47…
$7.2 = \bar{x}'$	542	0	0	(…
7.6	358	+1	+358	358
8.0	279	+2	+558	111…
8.4	99	+3	+297	891
8.8	15	+4	+60	240
9.2	1	+5	+5	25
	$\Sigma(f) = N = 2000$		$\Sigma(fz) = 257$	$\Sigma(fz^2) = \ldots$

$$\bar{x} = 7.2 + 0.4\,\frac{257}{2000} = 7.251\ \mu\text{m}$$

$$s^2 = 0.4^2\,\frac{4467 - 33.0}{1999} = 0.4^2 \times 2.218;$$

$s = 0.4\sqrt{2.218} = 0.596\ \mu$m without SHEPPARD's correction

$s^2 = 0.4^2(2.218 - 0.0833) = 0.4^2(2.135)$;

$s = 0.4\sqrt{2.135} = 0.584\ \mu$m with SHEPPARD's correction

10E. Quantiles of continuous distributions

Definition: In $p = F(x)$, x is known as the *quantile* (p), here given the symbol $Q(p)$ or x_p. Quantiles are thus the *inverse function* of $F(x)$; they are so-called parameters of position. The quantile has also been given the name fractile. On $F(x)$ see also (401) and (402).

The quantiles most commonly used are given special names: (4…

Quantile	Probability p
Quartile.............	$0.25 \times n$ $(n = 1, 2, 3, 4)$
Median	0.5 (= 2nd quartile)
Decile	$0.1 \times n$ $(n = 1, 2, \ldots, 10)$
Percentile	$0.01 \times n$ $(n = 1, 2, \ldots, 100)$

Interpretation of a quantile (p) of a continuous population:
$100p\%$ of the population lie below the quantile
$100(1-p)\%$ of the population lie above the quantile. (50…

Example 23. See Figure 8 (quartiles and median of a normal di… tribution), page 151.

Estimation

(*a*) *Ungrouped samples.* The quantile $Q(p)$ of a population is est… mated by calculating the corresponding quantile $Q(p)$ of a samp… taken from it. The sample values x are arranged in order of magn… tude [cf. (342)] and numbered serially, the smallest value receivin… the number 1. These *order numbers* are known as the *ranks* of th… sample values x, so that

$$x_1 < x_2 < x_3 < \cdots < x_N$$

The quantile $Q(p)$ thus corresponds to the sample value with th… rank $O(p)$:

$$O(p) = Np + 0.5\left(\text{for } \frac{1}{N} \leq p \leq \frac{N-1}{N}\right) \qquad (501a)$$

If $O(p)$ is a whole number, the quantile $Q(p)$ *coincides with th…* sample value; if $O(p)$ is a fraction, the quantile (p) *lies betwee…* the sample values with ranks adjacent to $O(p)$, i.e., between x_i and x_{i+1}. There would be little point in interpolating between thes… two values.

If the sequence of ordered sample values contains ties [cf. (346)] and $O(p)$ falls on or between the ranks of tied values, then $Q(p)$ is *given the magnitude of these tied values provided* that the number of such ties is small compared with the sample size. In samples with very many ties (few classes and high frequencies) there is no point in determining quantiles in accordance with (501a).

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_N}{N} =$$

($\bar{x}$ is read as 'x bar'.)

The *most efficient, unbiased* esti..

(*a*) when μ is known

$$s^2 = \frac{\Sigma (x - \mu)^2}{N} = \frac{S'_x}{N}; \text{ for}$$

(*b*) when μ is unknown

$$s^2 = \frac{\Sigma (x - \bar{x})^2}{N - 1} = \frac{S_x}{N - 1};$$

The calculation of S_x (this sy..
by the use of the following ...

$$\left.\begin{aligned} S_x &= \Sigma (x - \bar{x})^2 \\ &= \Sigma x^2 - N\bar{x}^2 \end{aligned}\right\} \text{ for } S'_x \text{ w}\cdot$$

$$= \Sigma x^2 - \bar{x} \Sigma x$$

$$= \Sigma x^2 - (\Sigma x)^2/N$$

$$[= s^2 (N - 1)]$$

The most efficient *asymptotically*
In practice the bias of s can us..
tion factors for eliminating th
normally distributed popul..

The most efficient unbiased esti
the most efficient asymptotically
is $s_{\bar{x}} = s/\sqrt{N}$. Cf. also (494).

Other estimates of σ will be

Example 21 [of (491)–(495)]. C
page 158,

then according to formula (491)

(493)

(492)

(494)

(495)

The results should finally be ..
in order not to imply an a. ...

10D. Estimates of μ and σ^2

Given the classes $x_1, x_2, \ldots, x$
classes $d = x_{i+1} - x_i$ and the f..
a provisional mean $\bar{x}'$ is chosen
now numbered. $\bar{x}'$ receives the
wards receive the numbers $z =$
the numbers $z = 1, 2, \ldots$

Classes ... $(\bar{x}' - 2)$ $(\bar{x}' - 1)$ $\bar{x}'$

z ... -2 -1 0

Then

$$\bar{x} = \bar{x}' + d\,\frac{\Sigma f z}{N}$$

$$s^2 = \frac{d^2}{N - 1}\left(\Sigma (f z^2) - \frac{(\Sigma \ldots}{\ldots}\right.$$

SHEPPARD's *correction*

:xample 24. Given the ranked sample

:	1 75	1 76	1.76	1.77	1.78	1.79	1 80	1 81	1 82	1.84	1.86
)	1	2	3	4	5	6	7	8	9	10	11
::	1.86	1 93	1 95	2 00	2 07	2.18	2 35	2 68	3 56	4 41	
):	12	13	14	15	16	17	18	19	20	21	

ı required to find the 1st quartile, median and percentile (0 7) In :ordance with (501a)

$O(0\ 25) = 0\ 25 \times 21 + 0\ 5 = 5\ 75$
[$Q(0\ 25)$ lies between 1.78 and 1.79]

$O(0\ 5) = 0\ 5 \times 21 + 0\ 5 = 11$
[$Q(0.5) = 1\ 86$ (note the tie)]

$O(0\ 7) = 0\ 7 \times 21 + 0\ 5 = 15\ 2$
[$Q(0\ 7)$ lies between 2 00 and 2 07]

) *Grouped samples.* Given are the ranked classes $x_1, x_2, \ldots x_i, \ldots x_n$, with class width $d = x_{i+1} - x_i$, and class fre- iencies $f_1, f_2, \ldots f_i, \ldots f_n$, where $f_1 + f_2 + \ldots + f_n = N$, *= sample size*

he cumulative frequencies are written as follows: $f_1 = (1)$, $f_1 + f_2 = F(2)$, $f_1 + f_2 + f_3 = F(3)$, up to $f_1 + f_2 + \ldots + f_n = F(i)$ Np is now compared with $F(i)$: (501b)

$Np = F(i)$, then $Q(p) = x_i + \frac{1}{2} d$

Np lies between $F(i)$ and $F(i+1)$, then $Q(p)$ lies be- ween $x_i + \frac{1}{2} d$ and $x_{i+1} + \frac{1}{2} d$

0F. Distribution-free confidence limits for quantiles of continuous distributions

Cf also section 8C, page 155)

limits in the sample are then

$$\left.\begin{aligned} &\text{for } p \leq 0\ 5 \quad O(p)_l = x_l + 1 \text{ and } O(p)_r = x_r \\ &\text{for } p > 0\ 5 \quad O(p)_l = N - x_r' + 1 \text{ and } O(p)_r = N - x_l' \end{aligned}\right\} \quad (502)$$

Example 25. For the sample in example 24 the 95% confidence limits are as follows

Quantile	Ranks		95% confidence limits
1st quartile	1 + 1 = 2	and 10	1 76 < Q (p) < 1 84
Median	5 + 1 = 6	and 16	1 79 < Q (p) < 2 07
Percentile (0 7)	21 − 12 + 1 = 10	and 21 − 1 = 20	1 84 < Q (p) < 3 56

10G. Relations between mode, median and mean of continuous distributions

The abscissa x of the maximum value of the density function $f(x)$ is known as the *mode* (503)

In practice the mode is of little importance On $f(x)$ see (400)

In one-peaked *symmetrical* distributions the *mode, median and mean are coincident*, but not in unsymmetrical distributions (cf Fig 31, page 165) The relationship between the three parameters is expressed by

Median $\sim$ ⅔ mean + ⅓ mode (504)

* In the case of large samples the time saved here will be offset by that lost in ranking the sample

Of main importance in practice is the *identity* of the *median* and th *mean* in *symmetrical* distributions the distribution-free confidenc limits for the median are valid also for the mean It follows that

If the population mean $\bar{x}$ of a sample coincides with either of the distribution-free confidence limits for the population median or lies outside them, then with a significance probability $\leq 2\alpha$, the sample *does not* originate from a symmetrical distribution (505

This is the basis of the sign test, which is easily carried out an also independent of the form of the population

10H. The sign test

(*a*) *Testing a sample for symmetry.* $\bar{x}$ is calculated, and the sampl values, including $\bar{x}$, are ranked The number $N(-)$ of sample

Example 26 In example 24 in section 10E, $\bar{x} = 2\ 130$, $N(-) =$ 16 For $N = 21$ and $2\alpha = 0\ 05$, the table on page 105 gives th levels 5–16 With a significance probability of 0 05, the sample *do not* originate from a symmetrical distribution

(*b*) *Testing of pair differences (differences between pairs of observations*

Example 27 Of 500 pair differences, 210 are negative Do the 500 differences differ on the average from zero ($2\alpha = 0\ 05$)? F $2\alpha = 0\ 05$ and $N = 500$ the table on page 105 gives the levels 227 273, so that the difference from zero is confirmed with the desir significance

tion involved increases rapidly with increasing sample size). F differences can also be examined by sequential analysis (cf sect 26, page 196)

11. The normal distribution

[Cf also section 6, page 151 For the meaning of 'normal' see (4!

11A. Definition and characteristics

The normal distribution is a *continuous* distribution, the pro bility density function for which is defined by

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \quad (5$$

(μ = mean, σ = standard deviation, for π and e see page 132)

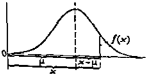


Fig 24

The curve of the probability density function

beings 9 feet tall or more should be 'possible' *. However, the word 'possible' is here inappropriate. 'Almost impossible' would be better, since the probability of extreme deviations from the mean decreases rapidly in the normal distribution.

If Prob ($|x - \mu| \gtrsim k\sigma$) $\lesssim 2\alpha$, 2α changes with increasing k as follows[10]: (507)

k	2α	k	2α
1	3.173105×10^{-1}	6	1.973175×10^{-9}
2	4.550026×10^{-2}	7	2.559625×10^{-12}
3	2.699796×10^{-3}	8	1.244192×10^{-15}
4	6.334248×10^{-5}	9	2.257177×10^{-19}
5	5.733031×10^{-7}	10	1.523971×10^{-23}

Remarks on (507): In accordance with the CHEBYSHEF Inequality [cf. (486)], the probability that in *any* distribution the variable x falls outside the limit $\mu \pm 3\sigma$, for example, is less than 1/9; as (507) shows, however, in the normal distribution it is only $\sim 3/1000$. On the other hand, these much closer limits are valid *only* when the population is *in fact* normal. The inverse deduction should therefore also be noted, namely that should a distribution for which the 3σ limits are regarded as adequate *not* be normal, then the probability that the variable x falls outside these limits is *not* 3/1000 but may be as large as 1/9. This is an excellent illustration of (478).

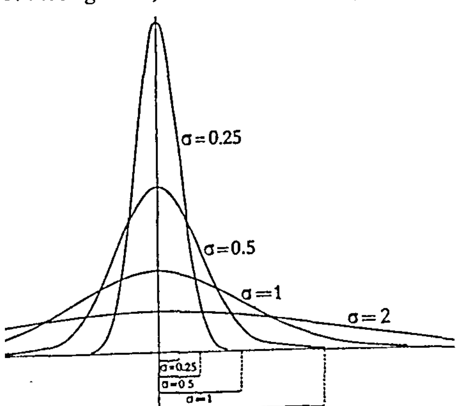
As with all symmetrical distributions, the mode, median and mean of the normal distribution are coincident. Their ordinate is the axis of symmetry of the curve of the probability density function [cf. Fig. 24 and (504)]. The most important consequences in practice are the following:

With a significance probability $\leq 2\alpha$, a sample that fails to pass the test for symmetry *does not* originate from a normally distributed population. (508)

If a *fairly small* sample passes the symmetry test [cf. also (474)], then the population from which it is drawn may still not be normal**. However, in significance tests (cf. page 158, 'Conditions requiring fulfilment') the stipulation of normality may be regarded as *almost* fulfilled. (509)

For *small* samples the sign test used for testing symmetry is relatively insensitive, that is, it will disclose an actual lack of symmetry in a population much more rarely with small samples than with large ones. For this reason (509) is valid only for *fairly small* samples. For small samples therefore, significance tests should be used – provided they are available – in which there are no conditions regarding symmetry or normality.

As (506) shows, the normal distribution is *fully* characterized by the two parameters μ and σ. The mean determines the *position* of the distribution with respect to the x axis, the standard deviation the *shape* of the curve: the larger σ is, the flatter the curve (cf. Fig. 25).



...ibutions with various standard deviations.

...n have any values, the number of possible nor... ...populations is infinite. If these are standardized according to (490a), they are *all* t... ...ized normal distributions.

...ay appear illogical, limits according to probability are ...lute limits. The statement, for instance, that there is an ...ight of the human body at, say, 8'3", would manifestly

11B. The standardized normal di...

If the quotient $(x - \mu)/\sigma$ in (490... becomes the *standardized normal distr... standard deviation*):

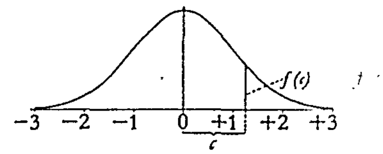


Fig. 26. Standardized normal distribution.

The symmetry of the distribution give... tionships:

Probability density function

$$f(0) = \max f(c) = 0.3\ldots$$
$$f(-c) = f(c)$$

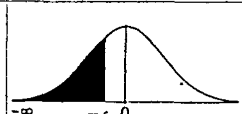
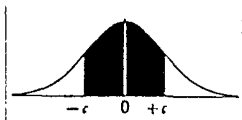
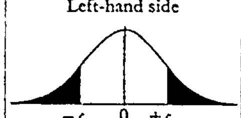
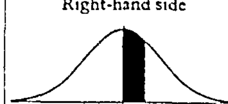
Probabilities

$$F(0) = \text{Prob}\,(c < 0) = \text{Prob}\,(c > 0) = \ldots$$
$$\text{Prob}\,(c < -k) = \text{Prob}\,(c > k)$$
$$= F(-k) = 1 - F(k)$$
$$\text{Prob}\,(-k \leq c \leq 0) = \text{Prob}\,(0 \leq c \leq k)$$

Quantiles

$$Q(\tfrac{1}{2}) = 0$$
$$Q(p) = -Q(1 - p)$$

11C. Tables of the standardized normal d... (pages 28–31)

Page	Table relates to	Left-hand side
28		Inverse functi... of the integral — = Quantile $Q(p)$ = $c(p)$ Argument p
29		Inverse function of the integral — = $c(p')$ Argument p'
30	Left-hand side  Right-hand side 	$1 - \int_{-c}^{c} f(c)\,dc$ = $2P$ Argument c *
31	Upper: ordinate $f(c)$, argument c. Cf. Fig. 26. Lower: inverse function of $1 - \int_{-c}^{c} f(c)\,dc$	

* For inverse function see page 31.

11D. Conversion of a normal distribution into t... standardized form and vice versa

(Cf. also section 10B, page 159)

The statement 'normal distribution with mean μ an... dard deviation σ' is here abbreviated to 'normal di... tion (μ; σ)'

The normal distribution (μ; σ) of the variable x is converted into the standardized normal distribution (0; 1) of the variable ε (and vice versa) by substituting X of (490) by ε. (519)

In this conversion the probabilities of the converted values remain *unchanged*, so that (520)

Prob $(x < x_k)$ = Prob $(\varepsilon < \varepsilon_k)$

Example 28. Given the normal distribution (174; 7), how large are the probabilities of the events $x < 160$, $x > 181$, $162 \leq x \leq 179$?

From (520)

$$\frac{160-174}{7} = -2, \quad \frac{181-174}{7} = 1,$$

$$\frac{162-174}{7} \sim -1.71, \quad \frac{179-174}{7} \sim 0.71$$

whence

Prob $(\varepsilon < -2) = F(-2) = 0.02275$ (from the right-hand table on page 28)

Prob $(\varepsilon > 1)$ = Prob $(\varepsilon < -1)$ [cf. (514a)] = 0.15866 (from the same table)

Prob $(-1.71 \leq \varepsilon \leq 0.71)$ Prob $(-1.71 \leq \varepsilon \leq 0)$, from (515),

Example 29. Given the normal distribution of example 28, it is required to find

(*a*) the one-sided confidence limit x_l for $1-\alpha_l = 0.95$
(*b*) the one-sided confidence limit x_r for $1-\alpha_r = 0.99$
(*c*) the two-sided confidence limits x_l and x_r for $1-2\alpha = 0.95$

Solution:

All confidence limits or significance limits are quantiles (α)

(*a*) ε_l is the quantile (α_l), where $\alpha_l = 1 - 0.95 = 0.05$ From the left-hand table on page 28, $\varepsilon_l = -1.6449$, whence $x_l = -1.6449 \times 7 + 174 = 162.4857$

and $x_r = 1.960 \times 7 + 174 = 187.72$. Even simpler to obtain are the two-sided limits, namely from the left-hand table on page 29, using the deviation ε, which can be read off directly by entering with the probability $1-2\alpha$

In connection with examples 28 and 29 it should be noted that, in practice, calculations are made with only as many decimal places as are required However, it is advisable for beginners to complete the calculation with the full number of decimal places and then round off the result to the required number

11E. The probit transformation

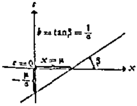


Fig 27a

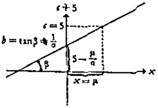


Fig 27b

The standardized variable $(x-\mu)/\sigma$ can be broken down in accordance with (34) into the fractions $-\mu/\sigma$ and x/σ If $-\mu/\sigma = a$ and $1/\sigma = b$, then

$$\varepsilon = a + bx, \text{ where } a = -b\mu \text{ and } b = 1/\sigma \qquad (521)$$

In accordance with (299), the curve of (521) is a *straight line* (cf Fig 27a)

The straight line of (521) passes through the point (μ, 0) When μ and σ are known its construction therefore only requires *one* other point to be calculated from (521) (522)

If the straight line in Fig 27b is displaced 5 units in the direction of the ordinate axis, then

$\varepsilon + 5$ = probit = $a + bx = 5 + b(x-\mu)$, whence $a = 5 - b\mu$ and $b = 1/\sigma$ (523)

The straight line of (523) passes through the point (μ; 5) When μ and σ are known its construction therefore only requires *one* other point to be calculated from (523) (524)

Since deviations of more than 5 σ are rare, the displacement of (521)–(523) means that in practice the majority of probit calcula-

on samples

If the ordinate and abscissa scales are linear scales (cf. the (525)

521

523

distributed

If the abscissa axis is divided linearly and the ordinate (526)

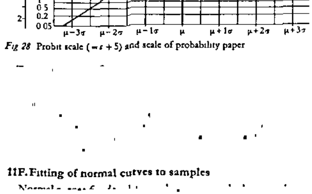


Fig 28 Probit scale ($=\varepsilon + 5$) and scale of probability paper

11F. Fitting of normal curves to samples

sample is compared with the normal curve fitted to it, with the result that these

beings 9 feet tall or more should be 'possible'*. However, the word 'possible' is here inappropriate. 'Almost impossible' would be better, since the probability of extreme deviations from the mean decreases rapidly in the normal distribution.

If Prob ($|x-\mu| \gtrsim k\sigma$) $\lesssim 2\alpha$, 2α changes with increasing k as follows[10]: (507)

k	2α	k	2α
1	3.173105×10^{-1}	6	1.973175×10^{-9}
2	4.550026×10^{-2}	7	2.559625×10^{-12}
3	2.699796×10^{-3}	8	1.244192×10^{-15}
4	6.334248×10^{-5}	9	2.257177×10^{-19}
5	5.733031×10^{-7}	10	1.523971×10^{-23}

Remarks on (507): In accordance with the CHEBYSHEF Inequality [cf. (486)], the probability that in *any* distribution the variable x falls outside the limit $\mu \pm 3\sigma$, for example, is less than 1/9; as (507) shows, however, in the normal distribution it is only $\sim 3/1000$. On the other hand, these much closer limits are valid *only* when the population is *in fact* normal. The inverse deduction should therefore also be noted, namely that should a distribution for which the 3σ limits are regarded as adequate *not* be normal, then the probability that the variable x falls outside these limits is *not* 3/1000 but may be as large as 1/9. This is an excellent illustration of (478).

As with all symmetrical distributions, the mode, median and mean of the normal distribution are coincident. Their ordinate is the axis of symmetry of the curve of the probability density function [cf. Fig. 24 and (504)]. The most important consequences in practice are the following:

With a significance probability $\leqq 2\alpha$, a sample that fails to pass the test for symmetry *does not* originate from a normally distributed population. (508)

If a *fairly small* sample passes the symmetry test [cf. also (474)], then the population from which it is drawn may still not be normal**. However, in significance tests (cf. page 158, 'Conditions requiring fulfilment') the stipulation of normality may be regarded as *almost* fulfilled. (509)

For *small* samples the sign test used for testing symmetry is relatively insensitive, that is, it will disclose an actual lack of symmetry in a population much more rarely with small samples than with large ones. For this reason (509) is valid only for *fairly small* samples. For small samples therefore, significance tests should be used – provided they are available – in which there are no conditions regarding symmetry or normality.

As (506) shows, the normal distribution is *fully* characterized by the two parameters μ and σ. The mean determines the *position* of the distribution with respect to the x axis, the standard deviation the *shape* of the curve: the larger σ is, the flatter the curve (cf. Fig. 25).

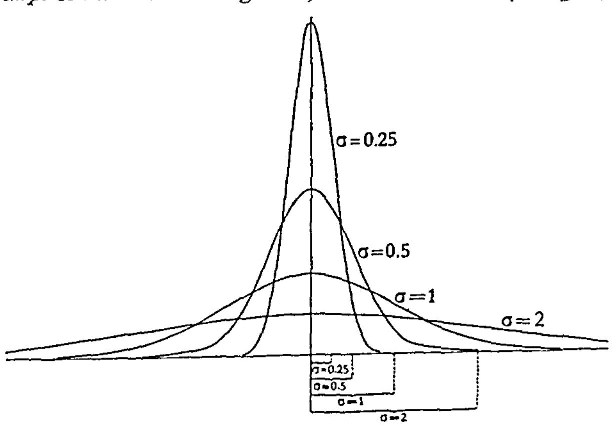


Fig. 25. Normal distributions with various standard deviations.

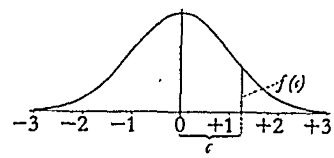
Since μ and σ can have any values, the number of possible normally distributed populations is infinite. If these are standardized according to (490a), they are *all* transformed into *single* standardized normal distributions.

* Although they may appear illogical, limits according to probability are more logical than absolute limits. The statement, for instance, that there is an *absolute* limit to the height of the human body at, say, 8′3″, would manifestly be untenable.

** Symmetrical distributions that are not normal also exist.

11B. The standardized normal distribution

If the quotient $(x-\mu)/\sigma$ in (490a) is denoted by c, then (becomes the *standardized normal distribution* (with *zero mean* and *standard deviation*):



$$f(c) = \frac{1}{\sqrt{2\pi}}\, e^{-c^2/2}$$

Fig. 26. Standardized normal distribution.

The symmetry of the distribution gives rise to the following relationships:

Probability density function

$$f(0) = \max f(c) = 0.398942 \quad (5$$

$$f(-c) = f(c) \quad (5$$

Probabilities

$$F(0) = \text{Prob}\,(c < 0) = \text{Prob}\,(c > 0) = \tfrac{1}{2} \quad (5$$

$$\text{Prob}\,(c < -k) = \text{Prob}\,(c > k) \quad \text{(a)}$$

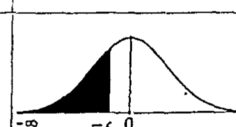
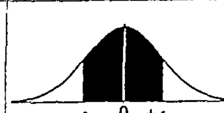
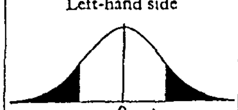
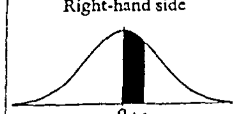
$$= F(-k) = 1 - F(k) \quad \text{(b)} \quad (51$$

$$\text{Prob}\,(-k \leqq c \leqq 0) = \text{Prob}\,(0 \leqq c \leqq k) \quad (51$$

Quantiles $\quad Q(\tfrac{1}{2}) = 0 \quad (51$

$$Q(p) = -Q(1-p) \quad (51$$

11C. Tables of the standardized normal distribution (pages 28–31)

Page	Table relates to	Left-hand side	Right-hand side
28		Inverse function of the integral → = Quantile $Q(p)$ = $c(p)$ Argument p	$\int_{-\infty}^{c} f(c)\,dc$ = $F(c)$ = $p(c)$ Argument c
29		Inverse function of the integral → = $c(p')$ Argument p'	$\int_{-c}^{c} f(c)\,dc$ = $p'(c)$ Argument c
30	Left-hand side 	$1 - \int_{-c}^{c} f(c)\,dc$ = $2P$ Argument c *	
	Right-hand side 		$\int_{0}^{c} f(c)\,dc$ = $\int_{-c}^{0} f(c)\,dc$ Argument c
31	Upper: ordinate $f(c)$, argument c. Cf. Fig. 26. Lower: inverse function of $1 - \int_{-c}^{c} f(c)\,dc$		

* For inverse function see page 31.

11D. Conversion of a normal distribution into the standardized form and vice versa

(Cf. also section 10B, page 159)

The statement 'normal distribution with mean μ and standard deviation σ' is here abbreviated to 'normal distribution (μ; σ)'. (518)

normal distribution $(\mu; \sigma)$ of the variable x is con-
d into the standardized normal distribution (0, 1) of
ariable c (and vice versa) by substituting X of (490) (519)

is conversion the probabilities of the converted values
in *unchanged*, so that
ob $(x < x_k)$ = Prob $(c < c_k)$ (520)

xample 28. Given the normal distribution (174; 7), how large are
probabilities of the events $x < 160$, $x > 181$, $162 \leq x \leq 179$?

n (520)

$$\frac{60-174}{7} = -2, \quad \frac{181-174}{7} = 1,$$

$$\frac{.62-174}{7} \sim -1\ 71, \quad \frac{179-174}{7} \sim 0\ 71$$

nce

'rob $(c < -2) = F(-2) = 0\ 02275$ (from the right-hand table
n page 28)

'rob $(c > 1)$ = Prob $(c < -1)$ [cf. (514a)] = 0 15866 (from the
ame table)

b $(-1.71 \leq c \leq 0.71)$ Prob $(-1\ 71 \leq c \leq 0)$, from (515),

page 30).

Example 29. Given the normal distribution of example 28, it is
quired to find

(*a*) the one-sided confidence limit x_l for $1 - \alpha_l = 0\ 95$

(*b*) the one-sided confidence limit x_r for $1 - \alpha_r = 0\ 99$

(*c*) the two-sided confidence limits x_l and x_r for $1 - 2\alpha = 0\ 95$.

Solution

All confidence limits or significance limits are quantiles (α).

(*a*) c_l is the quantile (α_l), where $\alpha_l = 1 - 0\ 95 = 0\ 05$ From the
ft-hand table on page 28, $c_l = -1\ 6449$, whence $x_l =$
$-1\ 6449 \times 7 + 174 = 162\ 4857$.

(*b*) c_r is the quantile $(1 - \alpha_r) = Q(0\ 99)$ From the left-hand table
n page 28, $c_r = 2\ 3263$, whence $x_r = 2\ 3263 \times 7 + 174 = 190\ 2841$

nd $x_r = 1\ 960 \times 7 + 174 = 187\ 72$ Even simpler to obtain are the
two-sided limits, namely from the left-hand table on page 29, using
he deviation c, which can be read off directly by entering with the
probability $1 - 2\alpha$

In connection with

11E. The probit transformation

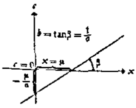


Fig 27a

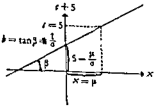


Fig 27b

The standardized variable $(x - \mu)/\sigma$ can be broken down in
accordance with (34) into the fractions $-\mu/\sigma$ and x/σ If $-\mu/\sigma = a$
and $1/\sigma = b$, then

$-b\mu$ and $b = 1/\sigma$ (521)

9), the curve of (521) is a *straight line* (cf

The straight line of (521) passes through the point $(\mu; 0)$.
When μ and σ are known its construction therefore only
requires *one* other point to be calculated from (521) (522)

If the straight line in Fig 27b is displaced 5 units in the direction
of the ordinate axis, then

$$c + 5 = \text{probit}^{11} = a + bx = 5 + b(x - \mu), \text{ whence} \quad a = 5 - b\mu \text{ and } b = 1/\sigma \qquad (523)$$

The straight line of (523) passes through the point $(\mu; 5)$
When μ and σ are known its construction therefore only
requires *one* other point to be calculated from (523) (524)

Since deviations of more than 5 σ are rare, the displacement of
(521)–(523) means that in practice the majority of probit calcula-

on samples

If the ordinate and abscissa scales are linear scales (cf the
extreme left-hand scale in Fig 28) and if now in place of
$F(x_p)$ the quantiles c_p or probits $c_p + 5$ are plotted in the
ordinate direction and x_p in the abscissa direction, then with (525)

distributed

If the abscissa axis is divided linearly and the ordinate (526)

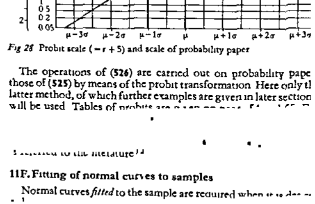


Fig 28 Probit scale ($= c + 5$) and scale of probability paper

The operations of (526) are carried out on probability pape
those of (525) by means of the probit transformation Here only t
latter method, of which further examples are given in later section
will be used Tables of probits

referred to the literature[14]

11F. Fitting of normal curves to samples

Normal curves *fitted* to the sample are required when

must be grouped, and the parameters μ and σ must be estimated by means of $\bar{x}$ and s in accordance with (491) and (492) [cf. the remarks on these equations and also (430)]. *In equations used in testing for goodness of fit, μ and σ are replaced by $\bar{x}$ and s.*

(a) Ungrouped samples

With ungrouped samples, empirical and fitted probit values can be compared only by eye. From (499) and (501a) it follows that

$$p_i = F(x_i) = \frac{O_i - 0.5}{N} \tag{527}$$

(O_i = rank of the individual sample value x_i; cf. section 10E, page 160)

The empirical and fitted probits can then be calculated from (527) in conjunction with (523)–(525).

Example 30. Given is the sample of example 24, section 10E, page 161. The mean $\bar{x}$ is 2.130, and the standard deviation s is 0.6713. The $F(x_i)$ values are first calculated according to (527): $F(x_1) = 0.5/21$, $F(x_2) = 1.5/21$, etc. [equation (31) is used here: $0.5/21 + 1/21 + \cdots$]. By multiplying by 100, these values are converted into percentages, which are then used in the table on pages 54 and 55 to obtain the probits. For $x_1, x_2, \ldots$ this gives the empirical probits 3.0, 3.5, 3.8, 4.0, etc. These values are plotted on millimetre paper in accordance with (525) to give the result shown in Figure 29.

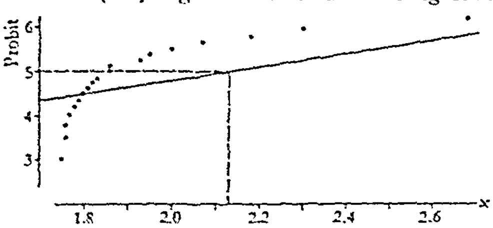


Fig. 29. Empirical probits and fitted probit line for the ungrouped sample of example 24, section 10E, page 161.

It will at once be seen that the points plotted deviate systematically from a straight line, indicating that it is very unlikely that the sample originates from a normally distributed population (as indeed was already clear from the result of the symmetry test of section 10H, page 161). If the sample had originated from a normal population, the points would have been distributed stochastically around the fitted probit line calculated in accordance with (523) and (524) from $\bar{x}$ and s in place of μ and σ.

(b) Grouped samples

In this case

$$f(x_i) = \frac{Nd}{\sigma} f(t_i), \quad t_i = \frac{x_i - \mu}{\sigma} \tag{528}$$

$$F(x_i + \tfrac{1}{2}d) = \Big(\sum_{1}^{i} f_i\Big)/N \tag{529}$$

(i = ranks of the classes x, $d = x_{i+1} - x_i$ = class width, f_i = frequency of the class i)

If both the fitted probability density *and* the cumulative distribution are to be calculated, then $x_i + \frac{1}{2}d$ is also used in (528) and the calculated ordinates plotted against $x_i + \frac{1}{2}d$, that is to say, at the *upper* limit of the class i. (528) gives the ordinates for the *middle* of the classes.

Example 31. Given is the sample of example 22, section 10D, page 160, with $\bar{x} = 7.251$, $s = 0.584$.

Table 1

$x + \frac{1}{2}d$	$x + \frac{1}{2}d - \bar{x}$	$(x + \frac{1}{2}d - \bar{x})/s = t$	$f(t)$	$f(t) \times Nd/s = f(x + \frac{1}{2}d)$
5.4	−1.851	−3.17	0.00262	3.6
5.8	−1.451	−2.48	0.01842	25.2
6.2	−1.051	−1.80	0.07895	108.2
6.6	−0.651	−1.11	0.21546	295.2
7.0	−0.251	−0.429	0.36387	498.5
7.4	0.149	0.255	0.38618	529.0
7.8	0.549	0.939	0.25671	351.7
8.2	0.949	1.62	0.10741	147.1
8.6	1.349	2.31	0.02768	37.9
9.0	1.749	2.99	0.00457	6.3

Calculation of the fitted probability density

The calculation is made as follows: The differences $x_i + \frac{1}{2}d$ are multiplied by $1/s$ to obtain the fitted t_i values [this can alsc carried out as a simple addition by using equation (31)]. For th deviations t, the corresponding ordinates $f(t)$ are obtained fr the upper table on page 31 [in this connection see also (51 Multiplication of these ordinates by Nd/s gives the required o: nates $f(x_i + \frac{1}{2}d)$. (Cf. Fig. 30, left.)

Calculation of the empirical probits

The values of $F(x_i + \frac{1}{2}d)$ are calculated from (529), multipl by 100, and the table on pages 54 and 55 entered to obtain t corresponding probits. The latter are plotted against $x_i + \frac{1}{2}d$ ordinates, giving the points of Figure 30, right.

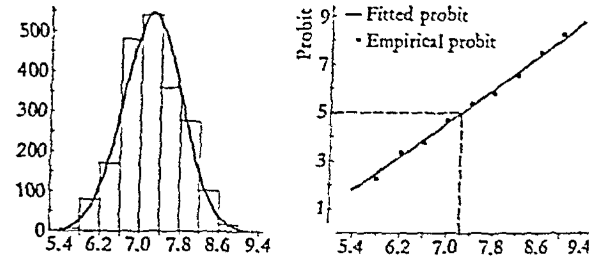


Fig. 30. Fitted probability density, empirical probits and fitted probit line fc the sample of example 22 in section 10D, page 160.

Calculation of the fitted probit line

The probit line is constructed according to (524). In this exampl it first passes through the point (7.25; 5). If the value $x = 5.4$, say is taken as the abscissa of the other necessary point, then from (523 the corresponding probit is $5 + 1.712\,(5.4 - 7.25) = 1.8$. When : straight line is drawn between these two points it is seen that th empirical probits all lie very close to it. The immediate impression given by Figure 30, right, is hardly such as to raise doubts that the population from which the sample is taken is other than a normally distributed one. That this impression is misleading, however, is demonstrated below.

Note that when the probability density is calculated as shown above, the two points required for the construction of the fitted probit line can be obtained by taking two remotely separated values from the column headed t of Table 1 and increasing them by 5.

Exact testing for non-normality by the χ^2 test

In this case the test is carried out by means of the t transformation, without probits, as follows (cf. Table 2 on page 165):

1. For calculation of the fitted t values for $x_i + \frac{1}{2}d$ according to (521) see column t of Table 1, which contains these values.
2. The $F(t)$ values corresponding to these fitted t values are obtained from the table on page 28. These are the fitted $F(t)$ values.
3. Multiplication of the fitted $F(t)$ values by the sample size N gives the fitted distribution of the cumulative absolute frequencies $H(x_i + \frac{1}{2}d)$.
4. From the differences $H(x_{i+1} + \frac{1}{2}d) - H(x_i + \frac{1}{2}d)$, the fitted absolute class frequencies f'_i are obtained.
5. From these the values of $(f_i - f'_i)^2/f'_i = \chi^2_i$ are calculated.
6. The sum of all the χ^2_i values is the required test statistic χ^2 with degrees of freedom $\nu = n - 2 - 1$, where n = number of classes.

The significance probability 2α of the χ^2 value obtained (cf. the table on page 36) is considerably smaller than 0.0005. Hence the population from which the sample originates is definitely *not* normally distributed, a result completely contrary to the impression gained by eye from the empirical probits (above).

Note that in the above calculation the sequence of the signs of the differences $f_i - f'_i$ should be looked at closely. The occurrence of pluses and minuses should vary randomly. If any systematic trend is detected, HALDANE's test (page 193) should be carried out, if there are systematic cycles, a test of randomness of runs (page 194) provided there are enough classes. The reason for this is that if the χ^2 test gives no significant result when the number of classes is large – as in the above example – then it can be assumed with reasonable certainty that the population is normally distributed *provided that there is random variation of the plus and minus runs.* If the latter is not the case then the χ^2 test needs supplementation. The test is also conditional on the classes being *independent* of one another. This is

Table 2

$x + \frac{1}{2}d$	$F(t)$	$F(t)\times N = H(x+\frac{1}{2}d)$	$H(x_{i+1}+\frac{1}{2}d)$ minus $H(x_i+\frac{1}{2}d) = f_i'$	f_i [cf (501b)]	$(f_i - f_i')^2/f_i' = \chi_i^2$
5 4	0 000 76	1 5	1 5* } = 11 6 } 13 1	5	5 01
5 8	0 006 57	13 1	58 8	78	6 27
6 2	0 035 93	71 9	195 1	144	13 38
6 6	0 133 50	267 0	400 2	479	15 52
7 0	0 333 60	667 2	537 9	542	0 03
7 4	0 602 57	1205 1	447 7	358	17 97
7 8	0 826 39	1652 8	242 0	279	5 66
8 2	0 947 38	1894 8	84 3	99	2 56
8 6	0 989 56	1979 1	18 1	15	0 53
9 0	0 998 61	1997 2	2 8	1	1 16
9 4	—*	—*	2000 0	2000	$\chi^2 = 68\ 09$ $\nu = 10-2-1 = 7$

* [illegible]

11G. Standard deviations of the quantiles of samples from normally distributed populations

The formulae given here are only *asymptotically* correct and [illegible]

better to use the procedure given in section 10F, page 161 (distribution-free confidence limits) and *not* calculate them by means of the standard deviations defined in the formulae given here

(Asymptotic)

$$\text{Standard deviation of } x_p = \sigma_{x_p} = \frac{1}{f(x_p)}\sqrt{\frac{p(1-p)}{N}} \qquad (530)$$

From (530) and (506) it follows that

$$\left.\begin{array}{l}\text{Standard}\\ \text{deviation of}\\ \text{the median}\end{array}\right\} x_{0\,5} = \sigma_{x_{0\,5}} = \sigma\sqrt{\frac{\pi}{2N}} = 1\ 2533\,\sigma\sqrt{\frac{1}{N}} \qquad (531)$$

In a normal distribution the median is identical with the mean μ. The median of a sample is therefore also an estimate of μ. The relative asymptotic efficiency of this estimate according to (433), (484) and (531) is

$$\frac{\sigma/\sqrt{N}}{\sigma\sqrt{\pi/2N}} = \sqrt{\frac{2}{\pi}} \sim 0\ 8$$

that is to say, about 80% of the efficiency of the estimate of μ made from $\tilde{x}$ according to (491)

11H. The logarithmic-normal (lognormal) distribution

The probability density function of this distribution is

$$\left.\begin{aligned} f(x) &= \frac{0\ 4343}{x\times\sigma_{\log x}}\times f(t),\\ t &= \frac{\log x - \mu_{\log x}}{\sigma_{\log x}}, \quad (0 < x < \infty)\end{aligned}\right\} \qquad (532)$$

The estimates of $\mu_{\log x}$ and $\sigma_{\log x}$ are $\bar{x}_{\log x}$ and $s_{\log x}$, calculated according to (491) and (492a and b) by substituting $\log x$ for x and $(\log x)^2$ for x^2

The logarithmic-normal distribution is unsymmetrical (cf Fig 31a) and has the following characteristics

$$\text{Mode} = \text{antilog}\,(\mu_{\log x} - 2\ 3026\,\sigma^2_{\log x}) \qquad (533)$$

$$\text{Median} = \text{antilog}\,\mu_{\log x} \qquad (534)$$

$$\text{Mean} = \text{antilog}\,(\mu_{\log x} + 1\ 1513\,\sigma^2_{\log x}) \qquad (535)$$

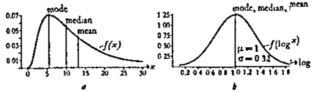


Fig 31 *a* Lognormal distribution *b* Transformation of *a*

If x is plotted on a logarithmic abscissa scale (or $\log x$ on a linear abscissa scale) the unsymmetrical distribution (532) is transformed into the symmetrical normal distribution

$$\left.\begin{aligned} f(\log x) &= \frac{1}{\sigma_{\log x}}\times f(t),\\ t &= \frac{\log x - \mu_{\log x}}{\sigma_{\log x}}, \quad (0 < x < \infty)\end{aligned}\right\} \qquad (536)$$

[for $\mu_{\log x}$ and $\sigma_{\log x}$ see (532)]

From (532) and (536) it follows that

$$f(x) = \frac{0\ 4343}{x}\times f(\log x) \qquad (537)$$

[illegible]

$$F(x_p) = F(\log x_p) = p \qquad (538)$$

Similarly for the quantiles

$$x_p = \text{antilog}\,(\log x_p) \qquad (539)$$

and for ungrouped samples

$$O(x_p) = O(\log x_p) \qquad (540)$$

(O = ranks of the individual sample values, cf section 10E, page 160)

From (536) and (538)–(540) it follows that [for (541)–(543)]

[illegible] 536 [illegible] (541)

If the transformation in (536) yields samples from a normally distributed population [cf (508) and section 11F, page 163], then any *tests* valid for the latter may be applied to these samples *The results of these tests will also be valid for the untransformed samples* (54[illegible]

For the estimation of the quantiles and their confidence [illegible] (54[illegible]

For *grouped* samples the following should be noted: the transformation $x \to \log x$ may be carried out only with the *individual values* If a sample is grouped into classes it must first be rearranged into an ungrouped sample The logarithms of the individual values are then obtained, [illegible] (54[illegible]

In natural processes many random variables are lognormal[illegible] distributed In all cases where the reaction of a body to a give[illegible] stimulus is proportional to the intensity of the stimulus and to th[illegible]

* The quantiles of a transformed variable are given by the transformed quantiles of the original variable provided that the transformation was made with an *increasing* function [$f(\log x)$ is an increasing function of x]

size of the body, the form of the distribution is lognormal. In practice, this applies particularly to toxicological and other similar biological studies, where logarithmic transformation of the variable x (dose) is a matter of routine.

11I. The addition theorem for the normal distribution

If $x_1, x_2, \ldots, x_k$ are stochastically independent, normally distributed variables with mean values $\mu_1, \mu_2, \ldots, \mu_k$ and variances $\sigma_1^2, \sigma_2^2, \ldots, \sigma_k^2$, then the variable

$$x = x_1 \pm x_2 \pm \cdots \pm x_k$$

is also normally distributed with mean

$$\mu = \mu_1 \pm \mu_2 \pm \cdots \pm \mu_k$$

and variance

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + \cdots + \sigma_k^2 \qquad (545)$$

In (545) it should be noted that the variances are also *additive when the mean μ is obtained from differences.*

11J. The central limit theorem

The importance of the normal distribution lies in the fact that under fairly general conditions, the sum of k stochastically independent variables *of any sort* converges stochastically with increasing k toward a normal distribution with mean

$$\mu = \mu_1 + \mu_2 + \cdots + \mu_k$$

and variance

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + \cdots + \sigma_k^2 \qquad (546)$$

From (545) the sum of normally distributed variables is *always* normally distributed, even when k is small. (546) is valid for variables distributed in *any* form, however, only when k approaches infinity. *In practice, the expression 'infinity' is interpreted liberally.* Thus, if for example in (546) the distributions all have the *same*, not too unsymmetrical form, then practically speaking their sum is normally distributed even when k is fairly small (50, 100, 200, ...). In other words, there will be a negligible error if the sample distributions are treated as normal.

In this publication, the statistical tables relating to sample distributions are so arranged that samples exceeding the tabulated sizes can for practical purposes be regarded as normally distributed. (547)

With *one* exception, *all* the sample distributions dealt with in this chapter converge toward the normal distribution in accordance with (546). The exception is the distribution of the extreme range (and of course that of the extreme deviations).

2. Distributions closely allied to the normal distribution

12A. The Student distribution

If in the standardized *normal* deviation $c = (x - \mu)/\sigma$ the standard deviation σ has to be replaced by its estimate s because σ is unknown and thus has to be estimated from the sample, then the standardized variable

$$t_\nu = \frac{x - \mu}{s_\nu} \quad (s_\nu \text{ independent of } x) \qquad (548)$$

has a probability density function

$$f(t \mid \nu) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma(\nu/2)\sqrt{\nu\pi}} \left(1 + \frac{t^2}{\nu}\right)^{-(\nu+1)/2}$$

where $\Gamma(x/2) = \begin{cases} (x/2-1)(x/2-2)\ldots 3 \times 2 \times 1 & \text{when } x \text{ is even} \\ (x/2-1)(x/2-2)\ldots 3/2 \times 1/2 \times \sqrt{\pi} & \text{when } x \text{ is odd} \end{cases} \qquad (549)$

ν is the number of *degrees of freedom* of t)

The Student distribution is independent of μ and σ; its f[...] determined only by the number of degrees of freedom [...] determination of the degrees of freedom will be described la[...] various individual cases.

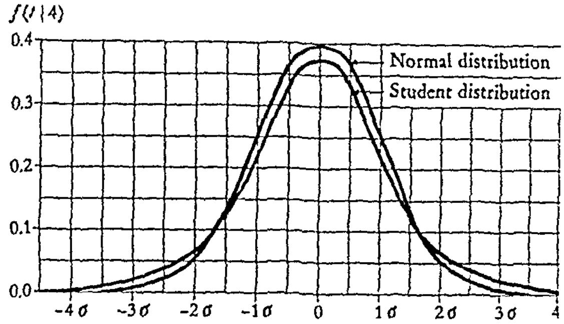


Fig. 32. Probability density of the normal distribution and of the Student [distri]bution with degrees of freedom $\nu = 4$.

The Student distribution (or t-distribution) is very similar [to the] normal distribution and converges toward it rapidly with in[creas]ing degrees of freedom. Its range of variation is from minus [infin]ity to infinity. It is continuous, *symmetrical* and bell-shaped, [but in] contrast to the normal distribution has more probability co[ncen]trated in the tails and less in the central part.

Equations (512)–(517) for the standardized normal distribution derived from the symmetry are also valid for the Student distribution when c is replaced by t.

Tables

In the tables on pages 32–35 the exact deviations t_0 for de[grees] of freedom ν between 1 and 200 are given for the following [inte]grals:

$$P\,(\text{of the table}) = \int_{t_0}^{\infty} f(t)\,dt = \text{Prob}\,(t > t_0) \qquad \text{(a)}$$

$$2P\,(\text{of the table}) = \int_{-\infty}^{-t_0} f(t)\,dt + \int_{t_0}^{\infty} f(t)\,dt = \text{Prob}\,(t < t_0) + \text{Prob}\,(t > t_0) \qquad \text{(b)}$$

In *one-tailed* tests (confidence limits) $\alpha = P$, in *two-tailed* tests (confidence limits) $2\alpha = 2P$. (c)

In accordance with (405b), the cumulative distribution $F(t) = \text{Prob}\,(t \leqq t_0)$ is

$$F(t_0) = 1 - \text{Prob}\,(t > t_0) = 1 - P = 1 - (551\text{a}) \qquad \text{(d)}$$

In the table on page 42 the exact deviations t_0^2 for degre[es of] freedom between 1 and 200 are given for the following inte[grals:]

$$P_r = \int_{t_0^2}^{\infty} f(t^2)\,dt^2 = \text{Prob}\,(t^2 > t_0^2) = 2\,\text{Prob}\,(t > t_0) \qquad \text{(a)}$$

$$\tfrac{1}{2} P_r = \tfrac{1}{2}\,(552\text{a}) \qquad \text{(b)}$$

For *one-tailed* tests $\alpha = \frac{1}{2}P$, for *two-tailed* tests $2\alpha = P$. (c)

For the relationship between the Student and F-distribution [see] (575).

12B. The χ^2 distribution

If $x_1, x_2, \ldots$ are stochastically independent observations [from] the *same normally distributed* population with mean μ and stan[dard] deviation σ, then the sum

$$\chi_\nu^2 = c_1^2 + c_2^2 + \cdots + c_i^2 + \cdots + c_\nu^2 = \sum_1^\nu c_i^2 \qquad ($$

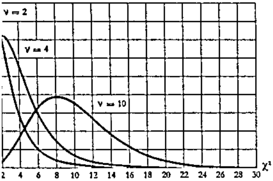
of the squares of the standardized deviations

$$c_i^2 = \left(\frac{x_i - \mu}{\sigma}\right)^2$$

has the probability density function

$$f(\chi^2|\nu) = \frac{1}{2^{\nu/2}\,\Gamma(\nu/2)}\, e^{-\chi^2/2}\,(\chi^2)^{(\nu-2)/2};\ (0 \leqq \chi^2 <$$

[ν is the number of degrees of freedom of χ^2; for Γ see



robability density functions of the χ^2 distribution with $\nu = 2, 4, 10$

5 . ! 549

ers

: $= \nu - 2$ (a)
ι μ $= \nu$ (b) (555)
nce $\sigma^2 = 2\nu$ (c)

ic convergence when $\nu \to \infty$

$\to 1$ (a)
stribution $\to$ Normal distribution $(\nu, \sqrt{2\nu})$, fairly slowly (b) (556)
^{2} distribution $\to$ Normal distribution $(\sqrt{2\nu - 1}, 1)^*$, faster than (b) (c)

imations for quantiles

entrally positioned quantiles [in accordance 56c)]

$\cdot \tfrac{1}{2}(c_p + \sqrt{2\nu - 1})^2$, $\nu > 30$ (a) (557)

xtreme quantiles[1,2]

$\nu\left(1 - \frac{2}{9\nu} + c_p\sqrt{\frac{2}{9\nu}}\right)^3$, $\nu > 30$ (b)

alculation of the quantiles 0 005, 0 025, 0 975 and 0 995 e confidence limits for λ of the POISSON distribution see

ple 32 [of (557)] Comparison between (a) and (b) The $\chi^2_{0.99;\ \nu=50}$ is required

$\sim \tfrac{1}{2}(1\ 96 + \sqrt{100 - 1})^2 = 70\ 922$

$\approx 50\left(1 - \frac{2}{450} + 1\ 96\sqrt{\frac{2}{450}}\right)^3 = 71\ 424$

t value is 71 420

ables on pages 36–39 the exact deviations χ^2_p for degrees n ν between 1 and 200 are given for the following inte-

the table) $= \int_{\chi^2_p}^{\infty} f(\chi^2)\,d\chi^2 = \text{Prob}(\chi^2 > \chi^2_p)$ (a)

the table) $= \tfrac{1}{2}$ (558 a) (b) (558)

the table) $= \int_0^{\chi^2_p} f(\chi^2)\,d\chi^2 = \text{Prob}(\chi^2 < \chi^2_p) = F(\chi^2_p)$ (c)

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$\tfrac{1}{2}\int_1$ (of the table) $= \tfrac{1}{2}$ (558c) (d)

For *one-tailed* χ^2 tests $\alpha = \tfrac{1}{2}\int_r$
For *two-tailed* χ^2 tests $2\alpha = 1\int_r$ (e)

With *one-sided* confidence limits for σ,
for *upper* limits $\alpha = 1\int_r$
for *lower* limits $\alpha = 1\int_l$ (f)
With *two-sided* confidence limits for σ:
for the *upper* limit $\alpha = \tfrac{1}{2}\int_r$
for the *lower* limit $\alpha = \tfrac{1}{2}\int_l$ $\alpha < 0\ 5$

The useful square root $\sqrt{\nu/\chi^2_p}$ for degrees of freedom between 1 and 200 is given on page 47 (*confidence factors for σ*) for the following quantiles

χ^2_p	Column $1-2\alpha$	χ^2_p	Column $1-2\alpha$
0 05 and 0 95	0 90	0 01 and 0 99	0 98
0 025 and 0 975	0 95	0 005 and 0 995	0 99

Relationships with other distributions

Normal distribution·

When $\nu = 1$, then $\chi^2_p = c^2_{(1+p)/2}$, that is
$\text{Prob}(\chi^2 < \chi^2_p) = 2\,\text{Prob}(0 < c_p)$

F-Distribution, see (576) and (577)

POISSON distribution

The probability that a POISSON variable with mean $\chi^2_p/2$ takes the value x is $\dfrac{e^{-\chi^2_p/2}(\chi^2_p/2)^x}{x!}$

This distribution is shown very clearly in Figure 44, page with $\lambda = \chi^2_p/2$, $x = \nu/2$.

It can be shown that if ν is even

$$\text{Prob}(\chi^2 > \chi^2_p \mid \nu = 2k) = \sum_{0}^{k-1} \frac{e^{-\chi^2_p/2}(\chi^2_p/2)^x}{x!}$$

For even numbers of degrees of freedom ν the following qu tiles can be calculated on the basis of (562) from the confide limits for λ of the POISSON distribution, pages 107 and 108:

Prob $(\chi^2 \le \chi^2_p) = p$	Argument (table on pp 107 and 108)	Page	χ^2_p equals
0 005	$x = \nu/2$	108	$2\lambda_l$
0 025	$x = \nu/2$	107	$2\lambda_l$
0 975	$x = (\nu/2) - 1$	107	$2\lambda_r$
0 995	$x = (\nu/2) - 1$	108	$2\lambda_r$

ν an even number

Example 33 [of (563)] Required | Solution
$\chi^2_{0.975;\ \nu=260}$ | $x = 130$, $\lambda_l = 108\ 61$; $\chi^2_p = 217$
$\chi^2_{0.975;\ \nu=260}$ | $x = 129$, $\lambda_r = 153\ 30$, $\chi^2_p = 306$

The value $\lambda_r = 153\ 30$ has been interpolated linearly·

$154\ 39 - {}^{1}/_{10}(154\ 39 - 143\ 52) = 153\ 303$

$\lambda_{129} - {}^{1}/_{10}(\lambda_{130} - \lambda_{120}) \sim \lambda_{129}$

The addition theorem for the χ^2 *distribution*

In equation (553) the sum can be broken up into any number parts, for example

$$\chi^2 = \underbrace{c_1^2 + c_2^2}_{= \chi^2_1(\nu = 2)} + \underbrace{c_3^2 + c_4^2 + c_5^2 + c_6^2}_{= \chi^2_2(\nu = 4)} + \underbrace{c_7^2 + \cdots}_{= \chi^2_3(\nu = \ldots)} \text{ etc.}$$

It follows that

If $\chi^2_1, \chi^2_2, \ldots, \chi^2_n$ are stochastically independent and the χ^2 distributions have the degrees of freedom $\nu_1, \nu_2, \ldots, \nu_n$ respectively, then the sum $\chi^2 = \chi^2_1 + \chi^2_2 + \cdots + \chi^2_n$ likewise has a χ^2 distribution with $\nu = \nu_1 + \nu_2 + \cdots + \nu_n$ degrees of freedom (56

There is also a division theorem for χ^2 on which the analysis of regression and variance is based. For further details the reader is referred to the literature.

χ^2 and sample variance

In accordance with (553), $\chi^2 = [\Sigma(x-\mu)^2]/\sigma^2$. If μ is replaced by $\bar{x}$, then from (493c), $\Sigma(x-\bar{x})^2 = (N-1)s^2$. If now $N-1$ is replaced by ν, then νs^2 is *eventually* obtained in place of $\Sigma(x-\mu)^2$. Intuitively it is surmised that

$$\chi_\nu^2 = \frac{\nu s^2}{\sigma^2}, \text{ where } \nu = \text{degrees of freedom of } s^2 \tag{565}$$

and this is a good guess. It should be noted that (565) is a second definition of χ^2 equivalent to (553) but valid *only* for *normally* distributed populations.

An important asymptotic property of χ^2

Given is a sample divided into n classes from a population *of any form*. If f_i is the observed frequency of the class i, where $f_1+f_2+\cdots+f_i+\cdots+f_n=N$, then f_i is known as the *empirical* (absolute) *frequency*. If p_i is the *given* or a *hypothetical* probability that the variable x will fall in the class i, where $p_1+p_2+\cdots+p_i+\cdots+p_n=1$, then Np_i is known as the *given* or the *hypothetical* (absolute) *frequency*. The empirical frequencies in the individual classes are random variables. In this case

$$\sum_1^n \frac{(f_i - Np_i)^2}{Np_i} \to \chi_\nu^2; \text{ where } \nu = n-1$$

when $\nu \to \infty$. (566)

(566) was discovered by K. PEARSON. The fact that it is exactly valid only when $\nu \to \infty$ is of little consequence in practice but gives rise to certain restrictions:

In tests for goodness of fit based on (566), the *samples* as a whole should *not* be *too small*, the *hypothetical* (absolute) *frequencies in the individual classes not below* $Np_i = 4$. If they are less than this, they should be increased to the required level by combining 2, 3, ... neighbouring classes. This is necessary, however, only when the number of classes is small. If ν is greater than (about) 8 and the sample size over 40, then it is permissible for Np_i in isolated classes to be as low as 1. (567)

As a rule the hypothetical frequencies are not given:

Theoretical (absolute) frequencies Np_i which have been calculated on the basis of *estimated* parameters are known as *fitted frequencies*; the theoretical distribution corresponding to them is known as the *fitted distribution*. (568)

(569)

(a) If k parameters must be estimated in the calculation of fitted frequencies, then the number of degrees of freedom for χ^2 defined by (566) is $\nu = n-1-k$, where n = number of classes.

(b) If m samples each grouped into n classes (in an $m \times n$ contingency table) are submitted to a χ^2 test based on (566), then the number of degrees of freedom for χ^2 is $\nu = (n-1)(m-1)$.

(c) In the special case, frequently encountered, of the 2×2 table, $\nu = 1$.

For an example of a χ^2 test with estimation of parameters see section 11 F (b), page 164. Another χ^2 test is described in section 23, page 191, in which further tests for frequency are dealt with.

In conclusion it should be noted that definitions (553) and (565) differ *fundamentally* from definition (566) in spite of the fact that the formulae are very similar: (553) and (565) are valid only for *normally distributed* populations, (566) is valid for populations of *any* form; (553) and (565), $\bar{x}$ and s are *continuous* variables, while in (566), f_i is a *discrete* variable.

When χ^2 tests are carried out with the aid of fitted distributions, care must be taken that the estimates made satisfy condition (430) and (431).

C. The F-distribution (variance-ratio distribution)

In the expression F-distribution, the letter F symbolizes *not* a cumulative distribution but the name of R. A. FISHER, the discoverer of the z-distribution, which is equivalent to the F-distribution[14].

If s_1^2 and s_2^2 are two stochastically independent estimates of the variance σ^2 of the *same normally distributed* population, then in accordance with (565)

$$s_1^2 = \sigma^2 \frac{\chi_1^2}{\nu_1} \text{ and } s_2^2 = \sigma^2 \frac{\chi_2^2}{\nu_2}$$

It follows that the quotient

$$F = \frac{s_1^2}{s_2^2} = \frac{\chi_1^2/\nu_1}{\chi_2^2/\nu_2}; \; 0 \leq F < \infty$$

(ν_1 and ν_2 are the degrees of freedom of s_1 and s_2 respectively)

has the probability density function

$$f(F) = \frac{\Gamma\left(\frac{\nu_1+\nu_2}{2}\right)}{\Gamma\left(\frac{\nu_1}{2}\right)\Gamma\left(\frac{\nu_2}{2}\right)} \nu_1^{\frac{\nu_1}{2}} \nu_2^{\frac{\nu_2}{2}} \frac{F^{\frac{\nu_1-2}{2}}}{(\nu_2+\nu_1 F)^{\frac{\nu_1+\nu_2}{2}}}; \; 0 \leq F < \infty$$

[for Γ see (549)]

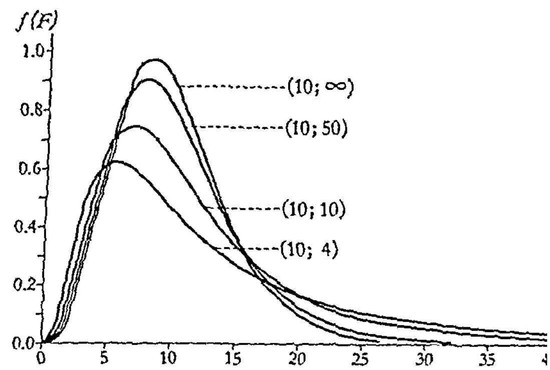


Fig. 34. Probability density functions of the F-distribution with various degrees of freedom (ν_1; ν_2).

The F-distribution is a continuous *unsymmetrical* distribution with a range of variation from zero to infinity.

Parameters

Mean $\quad \mu = \nu_2/(\nu_2 - 2); \; \nu_2 > 2$ (a)

Variance $\sigma^2 = \left(\frac{\nu_2}{\nu_2 - 2}\right)^2 \times \frac{2(\nu_1+\nu_2-2)}{\nu_1(\nu_2-4)}; \; \nu_2 > 4$ (b)

Interchange of ν_1 and ν_2

$$F_0(p; \nu_1; \nu_2) = 1/[F_0(1-p; \nu_2; \nu_1)]$$

In (573), p can be Prob $(F > F_0)$ just as well as Prob $(F < F_0)$

Tables

The values of F_0 given on pages 40 and 41 satisfy the following equation:

P (of the table) $= P_r = \int_{F_0}^{\infty} f(F)\,dF = \text{Prob}(F > F_0)$ (a)

In one-tailed tests $\alpha = P$, in two-tailed tests $2\alpha = 2P$ (b)

On the t^2 table of page 42 see (575) and (552). (c)

Relationships to other distributions

Student distribution:

$$\text{Prob}[(F > F_0) \mid 1; \nu_2] = \text{Prob}(t^2 > t_0^2 \mid \nu_2) = 2\,\text{Prob}(t > t_0 \mid \nu_2)$$

For $F(1; \nu_2)$ with ν_2 values between 1 and 200, the more comprehensive t^2 table on page 42 should therefore be used. For explanation see (552).

χ^2 distribution:

When F_p and χ_p^2 denote quantiles

$$F_p(\nu_1;\infty) = \frac{\chi^2_{p,\nu_1}}{\nu_1} \quad \text{(a)}$$

$$F_p(\infty;\nu_2) = \frac{\nu_2}{\chi^2_{1-p,\nu_2}} \quad \text{(b)} \qquad \text{(576)}$$

From (576) and (556a) it follows that

$$\left.\begin{array}{l} F(\nu_1;\infty) \to 1, \text{ when } \nu_1 \to \infty \\ F(\infty,\nu_2) \to 1, \text{ when } \nu_2 \to \infty \end{array}\right\} \text{that is, } F(\infty;\infty) = 1 \qquad \text{(577)}$$

Binomial distribution:

$$\text{Prob}\left[F(\nu_1;\nu_2) < \frac{N-x}{x+1} \times \frac{p}{1-p}\right] = \sum_{x+1}^{N} \binom{N}{k} p^k (1-p)^{N-k}$$

$$\left.\begin{array}{l} \text{where } N = \dfrac{\nu_1+\nu_2}{2} - 1 \\ x = \dfrac{\nu_1}{2} - 1 \end{array}\right\} \nu_1 \text{ and } \nu_2 \text{ are even numbers} \qquad \text{(578)}$$

On the basis of (578) the following quantiles F_α can be calculated from the confidence limits for p of the binomial distribution (pages 85–98)

Prob ($F<F_\alpha$)	Arguments (pages 85–98) Column	N	x	p	Quantile F_α
0.005	99 %	$\frac{\nu_1+\nu_2}{2} - 1$	$\frac{\nu_1}{2} - 1$	p_l	$\frac{\nu_2}{\nu_1} \times \frac{p}{1-p}$
0.025	95 %			p_l	
0.975	95 %			p_r	
0.995	99 %			p_r	

(579)

Example 34 $F_{0.995}(152, 36)$ is required. We have $N = 93$, $x = 75$, $p_r = 0.8993$ (from page 96), $p/(1-p) = 8.93049$, $\nu_2/\nu_1 = 0.236842$, $F_{0.995}(152, 36) = 2.12$.

13. The normally distributed population: Confidence and tolerance intervals

(Cf also section 8, page 154)

13A Confidence intervals for the mean μ

One-sided confidence interval with *single upper* limit

$\text{Prob}(-\infty < \mu < \bar{x} + k \times Sd) = 1 - \alpha$ [cf also (580d)] (a)

One sided confidence interval with *single lower* limit

$\text{Prob}(\bar{x} - k \times Sd < \mu < \infty) = 1 - \alpha$ [cf also (580d)] (b)

Two-sided confidence interval with symmetrical limits

$\text{Prob}(\bar{x} - k \times Sd < \mu < \bar{x} + k \times Sd) = 1 - 2\alpha$ [cf also (580d)] (c)

Factors $k \times Sd$ for (580a, b, c) (d) (580)

Equations	Degrees of freedom ν of s	k	Sd	Page (c, t or k)
(a) and (b)	> 200	$\lvert c_\alpha \rvert / \sqrt{N}$	σ or s	28
(a) and (b)	≤ 200	$t_{\nu,\alpha}/\sqrt{N}$	s_ν	32–35
(c)	> 200	k_1 or $\lvert c_\alpha \rvert/\sqrt{N}$	σ or s	k_1 43, c 28
(c)	≤ 200	k_1 or $t_{\nu,2\alpha}/\sqrt{N}$	s_ν	k_1 43, t 32–35

In the table on page 43 (for k_1) the number of degrees of freedom $\nu = N - 1$ is contained in the argument N. In this table the transition from t to c takes place at $N = 201$

13B. Tolerance intervals

Tolerance intervals without confidence probability

One-sided tolerance interval with *single upper* limit

$\text{Prob}(-\infty < x < m + k \times Sd) = 1 - \alpha = \beta_p$; [cf. also (581d)] (a)

One-sided tolerance interval with *single lower* limit

$\text{Prob}(m - k \times Sd < x < \infty) = 1 - \alpha = \beta_p$; [cf also (581d)] (b)

Two-sided tolerance interval with symmetrical limits

$\text{Prob}(m - k \times Sd < x < m + k \times Sd) = 1 - 2\alpha = \beta_p$ [cf. also (581d)] (c)

m, k and Sd for (581a, b, c) (d) (581)

Equations	Degrees of freedom ν of s	Known parameters or estimates	m	k	Sd	Page (c, t, k)
(a) and (b)	> 200	μ, σ or $\bar{x}, s$	μ or $\bar{x}$	$\lvert c_\alpha \rvert$	σ or s	28
(a) and (b)	≤ 100	$\bar{x}, \sigma$	$\bar{x}$	k_3*	σ	44, col 1
(a) and (b)	≤ 100	μ, s	μ	$t_{\nu,\alpha}$	s	32–35
(a) and (b)	≤ 100	$\bar{x}, s$	$\bar{x}$	k_4*	s	44, col 2
(c)	> 200	μ, σ or $\bar{x}, s$	μ or $\bar{x}$	$\lvert c_\alpha \rvert$	σ or s	28
(c)	≤ 100	$\bar{x}, \sigma$	$\bar{x}$	k_3	σ	44, col 1
(c)	≤ 100	μ, s	μ	$t_{\nu,2\alpha}$	s	32–35
(c)	≤ 100	$\bar{x}, s$	$\bar{x}$	k_4	s	44, col 2

* β_p in the table is selected as follows β_p (required) $= 1 - 2\alpha$, α is given

Tolerance intervals with confidence probability β_t

Equations (581a, b, c) are applicable with the following complementary equation [example of (581d)]

$$\text{Prob}[\text{Prob}(m - k \times Sd < x < m + k \times Sd) \geqq 1 - 2\alpha] = \beta_t$$

m, k and Sd for (581a, b, c) (582)

Equations	Degrees of freedom ν of s	Known parameters or estimates	m	k	Sd	Page (c, t, k)
(a) and (b)	≤ 100	$\bar{x}, \sigma$	$\bar{x}$	k_5*	σ	44, col 3
(a) and (b)	≤ 100	μ, s	μ	k_6*	s	44, col 4
(a) and (b)	≦ 1000	$\bar{x}, s$	$\bar{x}$	k_7	s	45–46
(c)	≤ 100	$\bar{x}, \sigma$	$\bar{x}$	k_5	σ	44, col 3
(c)	≤ 100	μ, s	μ	k_6	s	44, col 4
(c)	≦ 1000	$\bar{x}, s$	$\bar{x}$	k_7	s	45–46

* β_p in the table is selected as follows $\beta_p = 1 - 2\alpha$, α is given

The following equations are valid for the confidence and tolerance factors

$$k_1 = t_{2\alpha, N-1} \times 1/\sqrt{N} \text{ for } N \leq 201 \quad \text{(a)}$$

$$= \lvert c_\alpha \rvert \times 1/\sqrt{N} \text{ for } N > 201 \quad \text{(b)}$$

$$k_3 = \lvert c_\alpha \rvert \times \sqrt{1 + 1/N} \quad \text{(c)}$$

$$k_4 = t_{2\alpha, N-1} \times \sqrt{1 + 1/N} \quad \text{(d)} \qquad \text{(583)}$$

$$k_5 \quad \text{solution of } \int_{c'-k_5}^{c'+k_5} f(c)dc = \beta_p, \; (c' = c_{\beta_t}) \quad \text{(e)}$$

$$k_6 = \lvert c_{\alpha_p} \rvert \times \sqrt{(N-1)/\chi^2_{1-\beta_t, N-1}} \quad \text{(f)}$$

k_7 cf. Eisenhart et al [15], pages 108–109

13C. Confidence intervals for the standard deviation σ

From (583) it follows that

$$\left.\begin{array}{l} \text{Prob}(k_l s_\nu < \sigma < k_r s_\nu) = 1 - 2\alpha \\ \text{where } k_l = \sqrt{\nu/\chi^2_{\nu,1-\alpha}} \text{ and } k_r = \sqrt{\nu/\chi^2_{\nu,\alpha}} \end{array}\right\} \qquad \text{(584)}$$

Values of k_l and k_r for degrees of freedom between 1 and 100 are given in the left-hand table on page 47.

14. The normally distributed population: Extreme range and extreme deviations

14A. The extreme range

Definition

$$\left.\begin{array}{l}\text{If } x_1 \text{ is the lowest and } x_n \text{ the highest value of a sample of}\\ \text{size } n, \text{ then } (x_n - x_1) \text{ is the extreme range } w_n \text{ of this sample.}\end{array}\right\} \quad (585)$$

The standardized extreme range of a sample of size n from a population with standard deviation σ is

$$W_n = \frac{w_n}{\sigma} = \frac{x_n - x_1}{\sigma} \qquad (586)$$

The mean extreme range of m samples of size n from one and the same population is

$$\bar{w}_{m,n} = \frac{\sum_1^m w_n}{m} = \frac{\sum_1^m (x_n - x_1)}{m} \qquad (587)$$

and the standardized mean extreme range is

$$\bar{W}_{m,n} = \frac{\bar{w}_{m,n}}{\sigma} = \frac{\sum_1^m w_n}{m\sigma} = \frac{\sum_1^m (x_n - x_1)}{m\sigma} \qquad (588)$$

Since the extreme range w_n is merely a special case of the mean extreme range $\bar{w}_{m,n}$ with $m = 1$, only the mean extreme range will be referred to in the text that follows.

Mean extreme range as a multiple of σ

The expected value $\bar{W}_n$ of the extreme range of random samples of size n from a normally distributed population with unit standard deviation satisfies the relation

$$\bar{W}_{m,n} \underset{m \to \infty}{\longrightarrow} \bar{W}_n \qquad (589)$$

The upper right-hand table on page 47 gives values of $\bar{W}_n$ for he standardized normal distribution as multiples of σ[16]. (Many uthors use the symbol d_n in place of $\bar{W}_n$.)

σ as a fraction of the mean extreme range

The quotient

$$\frac{\bar{w}_{m,n}}{\bar{W}_n} = \bar{w}_{m,n} \times A_n \qquad (590)$$

ives an unbiased estimate of σ. Values of this quotient are given . the lower right-hand table on page 47.

The relative efficiency of (590) compared with that of the estimate [s^2 from (492a)] when $m = 1$ is[17]

n	2	3	4	5	6	10	15	20	50	100	∞
fficiency	1.00	0.99	0.98	0.96	0.93	0.85	0.77	0.70	0.49	0.34	0

For sample sizes between 2 and 10 there is thus little difference tween the two estimates. Within this range (590) is useful as a *bid method of estimating* σ but *it should not be used in place of s in a ndard t test.*

For larger samples the extreme range of σ can likewise be ac- rately estimated, namely by dividing the sample into a number of *independent* subgroups of the same size between 2 and 10 and ...ing their extreme ranges. In accordance with (588), the ... *of these ranges is then the mean extreme range.* However, a subdivision must be effected by a *random selection* among the ...lable sample values. If there is no natural method of doing this ch as using the order in time of obtaining the sample values), dom numbers may be used, but the time needed to carry out the division will tend to nullify the advantages of the more rapid culation.

Overlapping groups must of course be avoid $x_1 - x_2$, $x_2 - x_3$, ..., since these would obviously r dependent.

$\sigma_{\bar{x}}$ as a fraction of the mean extreme range

The quotient

$$\frac{\bar{w}_{m,n}}{\bar{W}_n \sqrt{mn}} = \bar{w}_{m,n} \times A_{m,n}$$

where mn = sample size N, gives an unbiased estim dard deviation $\sigma_{\bar{x}}$ of the estimate $\bar{x}$. Values of the f

$$A_{m,n} = 1/(\bar{W}_n \times \sqrt{mn})$$

are given in the table on page 48.

Example 36 (section 14A). Given is the sample 3.(2.08, 2.10, 2.67. The estimates of σ and $\sigma_{\bar{x}}$ on the b treme range or mean extreme range are

(a) 1 extreme range

$$1.34 - 3.00: \quad \text{range} = 1.66 \quad \begin{array}{l}\sigma' = 1.66 \times 0.3\\ \sigma'_{\bar{x}} = 1.66 \times 0.1\end{array}$$

(b) 2 extreme ranges

$$\left.\begin{array}{l}1.34 - 3.00\\ 2.08 - 2.67\end{array}\right\} \begin{array}{l}\text{mean}\\ \text{range}\end{array} = 1.125 \quad \begin{array}{l}\sigma' = 1.125 \times 0.59\\ \sigma'_{\bar{x}} = 1.125 \times 0.24\end{array}$$

(c) 3 extreme ranges

$$\left.\begin{array}{l}1.56 - 3.00\\ 1.34 - 2.08\\ 2.10 - 2.67\end{array}\right\} \begin{array}{l}\text{mean}\\ \text{range}\end{array} = 0.91\dot{6} \quad \begin{array}{l}\sigma' = 0.91\dot{6} \times 0.88\\ \sigma'_{\bar{x}} = 0.91\dot{6} \times 0.36\end{array}$$

For comparison, σ can be estimated using (492b) wit $s = 0.63257$. In order to correct the bias of this estim be multiplied by the factor $k_s = 1.0509$ (see the left-ha page 47, column k_s), giving the result $s = 0.665$ and $s_{\bar{x}}$

All the above estimates may be regarded as equally though the agreement between s and the estimates (a) striking, this does not mean that estimate (c) is not a further sample from the same population could result i nearer to (c).

14B. Testing extreme ranges and extreme deviation

The 'studentized' extreme range (table on page 51, sample si

In the test quotients

$$\frac{x_N - x_1}{s_\nu}$$

(ν = degrees of freedom of s; $x_1 < x_2 < \cdots < x_N$)

s is an estimate calculated from a sample *different* fron *dependent* of the sample to be tested but originating from population. If the test quotient attains or exceeds the lev table corresponding to the degrees of freedom ν, and th size N, then the extreme range in question is *too large* (sig probability α).

If σ is known, the levels at $\nu = \infty$ should be used. If th size exceeds the range of the table, testing should be carrie cording to (596d) for sample sizes between 21 and 25 and ing to (595) for still larger samples, *if it is desired to test extre*

The 'studentized' extreme deviation (table on page 52, sample s

In the test quotients

$$\frac{x_N - \bar{x}}{s_\nu} \quad \text{or} \quad \frac{\bar{x} - x_1}{s_\nu}$$

(ν = degrees of freedom of s; $x_1 < x_2 < \cdots < x_N$)

s has the same meaning as in (592). If σ is known, the l $\nu = \infty$ should be used. If the test quotient attains or exce level in the table corresponding to the degrees of freedom the sample size N, then the extreme range in question is *t* (significance probability α).

If the sample size exceeds the range of the table, testing be carried out according to (596c and d) for sample sizes b 10 and 25 and according to (595) for still larger samples.

standardized extreme deviation (upper table on page 52)

We have

$$\text{Prob}\,(\epsilon \leq \epsilon_e) = \left[\int_{-\infty}^{\epsilon_e} f(\epsilon)\,d\epsilon\right]^N, \text{ for } \epsilon_e \text{ see (595)} \quad \text{(a)}$$

$$\text{Prob}\,(-\epsilon_e \leq \epsilon \leq \epsilon_e) = \left[\int_{-\epsilon_e}^{\epsilon_e} f(\epsilon)\,d\epsilon\right]^N \quad \text{(b)} \qquad \text{(594)*}$$

(ϵ_e = standardized extreme deviation; N = sample size)

In the test quotients

$$\frac{x_N - \mu}{\sigma} \text{ or } \frac{\mu - x_1}{\sigma} = \epsilon_e \qquad (595)$$

the symbols have the customary meaning For sample sizes over ..., μ and σ can be replaced by $\bar{x}$ and s For smaller samples (593) should be used.

Testing extreme values of a sample on the basis of their own attributes[18] (upper left-hand table on page 53, sample size 3–25)

When no independent information on the standard deviation of the population is available, extreme deviations in samples up to a size of 25 can be tested by means of the following quotients:

Sample size N	Quotient		Sample size N	Quotient	
3–7	$\left\lvert\dfrac{x_N - x_{N-1}}{x_N - x_1}\right\rvert$	(a)	11–13	$\left\lvert\dfrac{x_N - x_{N-2}}{x_N - x_2}\right\rvert$	(c)
8–10	$\left\lvert\dfrac{x_N - x_{N-1}}{x_N - x_2}\right\rvert$	(b)	14–25	$\left\lvert\dfrac{x_N - x_{N-2}}{x_N - x_3}\right\rvert$	(d)

(596)

where $x_1 < x_2 < \ldots < x_N$, when a right-hand extreme value is tested,
$x_N < x_{N-1} < \ldots < x_1$, when a left-hand extreme value is tested

With samples of over 25, (595) should be used with μ and σ replaced by $\bar{x}$ and s

General considerations in testing extreme values

It is common for extreme values to be ignored, often without comment by the author and without their first being tested statistically Occasionally they are even eliminated *before* the experimental data are put into the hands of the statistician This is clearly undesirable, for in some situations extreme values are often the most

reveals a causal circumstance accounting for its existence Examples would be an error made in measurements or calculations, the un-

is to contain extreme values of the population. A small sample containing an extreme value can give a completely false picture of the population it represents In such cases the extreme value *may be ignored* However, it is advisable to use a small significance probability

peculiarly dependent on this condition of normality

* This formula is derived from (382) and (483 a) or (487 c)

Special considerations in testing extreme values

If testing in accordance with (592) results in the postulated signifi-

It is permissible to test extreme values more than once in the same sample. In this case the sample size must be reduced by one after each rejection before a new test is made The resulting level of significance α_{res} for the total number k of significant tests then has the *very approximate* order of magnitude

$$\alpha_{res} \sim 1 - (1 - \alpha_1)(1 - \alpha_2) \ldots (1 - \alpha_k)$$

Example 37. The sample of example 24, page 160, is to be tested using (596 d).

1st test ($N = 21$)

Right-hand extreme deviate $\dfrac{4.41 - 2.68}{4.41 - 1.76} = 0.653$, deviate is too large ($\alpha \ll 0.005$)

2nd test ($N = 20$)

Right-hand extreme deviate $\dfrac{3.56 - 2.35}{3.56 - 1.76} = 0.672$; deviate is too large ($\alpha \ll 0.005$)

Only the *5th test* gives no further significant deviation

After two deletions $\alpha_{res} \sim 1 - (\gg 0.995)(\gg 0.995) < 0.01$, if the sample were from a normally distributed population This is not the case (cf section 10H, page 161), so that the extreme values may on no account be rejected

15. The normally distributed population: Comparison of a sample with the hypothetical population

15A Comparison of the sample and population standard deviations s and σ (or of the variances s^2 and σ^2)

The confidence limits for σ are obtained from (584), those for σ^2 analogously by replacing s by s^2 and k by k^2 The hypothetical σ or σ^2 is then compared with these limits and the result interpreted in accordance with (476)

15B. Comparison of the sample and population means $\bar{x}$ and μ

Comparison of the estimate $\bar{x}$ with the hypothetical mean is made by means of the test quotients given in (598)–(602), the numerical value of the quotient being compared with the limit given:

If the test quotient is *smaller* than the limit, then the result is interpreted in accordance with (474) or (475) If it attains or exceeds the limit, then

	Significance in brackets	
	One tailed test	Two tailed test
When $\bar{x} - \mu < 0$	$\bar{x} < \mu\,(\alpha)$	$\bar{x} \neq \mu\,(2\alpha)$
When $\bar{x} - \mu > 0$	$\bar{x} > \mu\,(\alpha)$	

(597)

The ϵ-test (normal distribution)

Applicability When σ is known or when the degrees of freedom of $s = N - 1 > 200$

Test quotient	Significance limit	
$\dfrac{\lvert\bar{x} - \mu\rvert\sqrt{N}}{\sigma}$, or $\dfrac{\lvert\bar{x} - \mu\rvert\sqrt{N}}{s_{N-1}}$, $N > 201$	$\lvert\epsilon_\alpha\rvert$, page 28	(a)
$\dfrac{(\bar{x} - \mu)^2 N}{\sigma^2}$, or $\dfrac{(\bar{x} - \mu)^2 N}{s^2_{N-1}}$, $N > 201$	$\chi^2_{\nu=1}$, page 36, $\alpha = \tfrac{1}{2}\int_\nu$, $2\alpha = 1\int_\nu$	(b)
$\dfrac{\lvert\bar{x} - \mu\rvert}{s_{N-1}}$; $N > 201$	$\epsilon/\sqrt{N}$ = confidence factor k_s, page 43	(c)

(598)

The t-test (Student distribution)

Applicability: When σ is unknown and the degrees of freedom of $s = N-1 \leq 200$

Test quotient	Significance limit		
$\dfrac{\lvert\bar{x}-\mu\rvert\sqrt{N}}{s_{N-1}}$; $N \leq 201$	t_{N-1}, pages 32–35; $\alpha = P$, $2\alpha = 2P$	(a)	(599)
$\dfrac{(\bar{x}-\mu)^2 N}{s^2_{N-1}}$; $N \leq 201$	t^2_{N-1}, page 42; $\alpha = \frac{1}{2}P$, $2\alpha = P$; cf. (552)	(b)	
$\dfrac{\lvert\bar{x}-\mu\rvert}{s_{N-1}}$; $N \leq 201$	$t_{N-1}/\sqrt{N}$ = confidence factor k_1, page 43	(c)	

Lord's test based on the extreme range[19]

Applicability: Samples of size $N \leq 20$ (a) and $N > 20$ (b)

Test quotient	*Significance limit*		
$\dfrac{\lvert\bar{x}-\mu\rvert}{x_N - x_1}$; $N \leq 20$; $x_1 < x_2 < \cdots < x_N$	Page 53, middle left-hand table	(a)	(600)
$\dfrac{\lvert\bar{x}-\mu\rvert\, m}{[\Sigma(x_n - x_1)]\, A_{m,n}}$; $m \times n = N$	Page 49; $A_{m,n}$ page 48	(b)	

m = number of subgroups of size n (cf. section 14A, page 170) in which $x_1 < x_2 < \cdots < x_n$

The midrange test based on the extreme range[20]

Applicability: Samples of size $N \leq 10$

Test quotient	Significance limit	
$\dfrac{\lvert x_N + x_1 - 2\mu\rvert}{x_N - x_1}$; $N \leq 10$	Page 53, upper right-hand table	(601)

Walsh test[20, 21]

Applicability: Samples of size $4 \leq N \leq 14$ from *any symmetrical* population

Test quotient	Significance limit	
Page 53, lower right-hand table	Page 53, lower right-hand table	(602)

Note that while the use of (598b) and (599b) involves the squaring of $(\bar{x}-\mu)$ it obviates extracting the square root of s^2 (provided s is not required). The use of (598c) and (599c) avoids the multiplication by $\sqrt{N}$, with the further advantage that the transition from t to c in using the table on page 43 is quite 'automatic'.

(600)–(602) are straightforward *rapid tests* [especially (601)] in which even $\bar{x}$ does not need to be calculated. Within the tabulated range their power is practically the same as that of (599). The Walsh test is suitable not only for normal but also for *any* other symmetrical distribution. In this case, the significance probability for N up to 8 is somewhat higher than that in the table. For $N > 8$ the values in the table are exact.

When a calculating machine is not available, multiplication is faster than division. In this event, the significance limit should be multiplied by the divisor of the test quotient in order to obtain the limit for the dividend.

Example 38. When t is the limit for $\dfrac{\lvert x-\mu\rvert\sqrt{N}}{s}$, then ts is the limit for $\lvert x-\mu\rvert\sqrt{N}$.

16. The normally distributed population: Comparison of two samples

In comparing two samples, the following hypotheses concerning the parameters of the original populations must be taken into consideration:

$$\sigma_1^2 = \sigma_2^2 \quad \left\{ \begin{array}{ll} \mu_1 = \mu_2 & \text{(a)} \\ \mu_1 \neq \mu_2 & \text{(b)} \end{array} \right\} \quad (603)$$

$$\sigma_1^2 \neq \sigma_2^2 \quad \left\{ \begin{array}{ll} \mu_1 = \mu_2 & \text{(a)} \\ \mu_1 \neq \mu_2 & \text{(b)} \end{array} \right\} \quad (604)$$

16A. Comparison of variances

The test quotient for the hypothesis $(\sigma_1^2 = \sigma_2^2)$ (603) is (570), in which the *larger of the two sample variances must always be made the numerator*. This means that renumbering of the variances with respect to the *indices of the table* is necessary when s_1^2 (from sample 1) is smaller than s_2^2. *The number of degrees of freedom* ν_1 *in the tables on pages 40 and 41 is always that of the numerator of* (570). (6

s_1^2 and s_2^2 must be calculated from (492). Their degrees of freedom are $\nu_1 = N_1 - 1$ and $\nu_2 = N_2 - 1$.

If the test quotient is *smaller* than the significance limit F in the table on pages 40 and 41, then in accordance with (474) it can be assumed that $\sigma_1^2 = \sigma_2^2$. In this case the means are tested by the procedure given in section 16B below. If the test quotient *attains* or *exceeds* the significance limit F, then $\sigma_1^2 > \sigma_2^2$ (significance probability $\alpha = P$) or $\sigma_1^2 \neq \sigma_2^2$ (significance probability $2\alpha = 2P$). The means are tested by the procedure given in section 16C, page 17

16B. Comparison of means when $\sigma_1^2 = \sigma_2^2$

The following symbols are used here:

$$\lvert\bar{x}_1 - \bar{x}_2\rvert = d \text{ and } \lvert\mu_1 - \mu_2\rvert = \mathbf{d} \quad (606$$

The estimate of the common standard deviation $\sigma = \sigma_1 = \sigma_2$ i

$$\left. \begin{array}{l} s = \sqrt{\dfrac{S_1 + S_2}{N_1 + N_2 - 2}};\ S_1 \text{ and } S_2 \text{ from (493)} \\ \nu_s = \nu_1 + \nu_2 = N_1 + N_2 - 2 \end{array} \right\} \quad (607$$

The estimate of the standard deviation of the difference $\mathbf{d}$ is

$$s_d = s\sqrt{\frac{1}{N_1} + \frac{1}{N_2}};\ s \text{ from (607)};\ \nu_{s_d} = N_1 + N_2 - 2 \quad (608)$$

If σ is known, s is replaced by σ in (608). If $N_1 = 1$, then $s_d = s\sqrt{1 + 1/N_2}$, $\nu = N_2 - 1$; cf. also (452) and (583c and e).

The test quotients for the hypotheses $(\mu_1 = \mu_2 \mid \sigma_1^2 = \sigma_2^2)$ are

if σ is known or $\nu > 200$

d/σ_d or d/s_d; limit $\lvert c_\alpha\rvert$, page 28 (a)

when $\nu \leq 200$

d/s_d; limit t_ν, pages 32–35; $\alpha = P$, $2\alpha = 2P$ (b) (609)

or

d^2/s_d^2; limit t_ν^2 [$= F(1;\nu)$], page 42; $\alpha = \frac{1}{2}P$, $2\alpha = P$ (c)

If the test quotient *attains* or *exceeds* the significance limit, then this is considered as evidence that $\mu_1 \neq \mu_2$. In this case it is often desirable to test the hypothesis $(\mu_1 - \mu_2 = \mathbf{d} \mid \sigma_1^2 = \sigma_2^2)$:

The test quotients are obtained by replacing d in (609) by $\lvert d - \mathbf{d}\rvert$. If the quotient exceeds the significance limit, then this is considered as evidence that $\mu_1 - \mu_2 \neq \mathbf{d}$. (610)

The confidence limits for $\mathbf{d}$ are

$$\left. \begin{array}{ll} \text{two-sided} & \\ \text{Prob}\,(d - t_{\nu,\alpha} \times s_d \leq \mathbf{d} \leq d + t_{\nu,\alpha} \times s_d) = 1 - 2\alpha & \text{(a)} \\ \text{one-sided with a single upper limit} & \\ \text{Prob}\,(\mathbf{d} \leq d + t_{\nu,\alpha} \times s_d) = 1 - \alpha & \text{(b)} \end{array} \right\} \quad (611)$$

If the test quotient in (609) is *smaller* than the significance limit, then it may be assumed in accordance with (474) that $\mu_1 = \mu_2$. Since also $\sigma_1^2 = \sigma_2^2$, the conclusion may be drawn that the two samples 1 and 2 originated from the same population with mean μ and variance σ^2. Estimates of these parameters are

$$\bar{x} = \frac{\sum\limits_1^{N_1} x_1 + \sum\limits_1^{N_2} x_2}{N_1 + N_2} = \frac{N_1\bar{x}_1 + N_2\bar{x}_2}{N_1 + N_2} \quad (612)$$

$$\left. \begin{array}{l} s^2 = \dfrac{S_1 + S_2 + \dfrac{\left(\sum\limits_1^{N_1} x_1\right)^2}{N_1} + \dfrac{\left(\sum\limits_1^{N_2} x_2\right)^2}{N_2} - \dfrac{\left(\sum\limits_1^{N_1} x_1 + \sum\limits_1^{N_2} x_2\right)^2}{N_1 + N_2}}{N_1 + N_2 - 1} \\ \quad = \dfrac{\nu_1 s_1^2 + \nu_2 s_2^2 + N_1\bar{x}_1^2 + N_2\bar{x}_2^2 - \dfrac{(N_1\bar{x}_1 + N_2\bar{x}_2)^2}{N_1 + N_2}}{N_1 + N_2 - 1} \end{array} \right\} \quad (613)$$

where $\nu_s = N_1 + N_2 - 1$; S_1 and S_2 from (493).

16C. Comparison of means when $\sigma_1^2 \neq \sigma_2^2$

If σ_1 and σ_2 are known, or $N_1 + N_2 > 200$, then

$$\sigma_d = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}} \text{ and } s_d = \sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}} \qquad (614)$$

and the test quotients

$$\frac{d}{\sigma_d} \text{ and } \frac{d}{s_d} \text{ or } \frac{|d - \mathfrak{d}|}{\sigma_d} \text{ and } \frac{|d - \mathfrak{d}|}{s_d} \qquad (615)$$

have the same limits as (609a)

If σ_1 and σ_2 are unknown, then the test quotients

$$\frac{d}{s_d} \text{ and } \frac{|d - \mathfrak{d}|}{s_d} \qquad (616)$$

have the same limits as (609b)[63], where

$$s_d = \sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}} \qquad (a)$$

$$\nu = \frac{1}{k^2/\nu_1 + (1-k)^2/\nu_2} \qquad (b) \qquad (617)$$

(ν_1 and ν_2 are degrees of freedom of s_1 and s_2 respectively)

$$k = \frac{N_2 s_1^2}{N_2 s_1^2 + N_1 s_2^2} \qquad (c)$$

16D. Testing pair differences

When two analytical methods can be tried out on the same substrate, or two methods of treatment on the same individual, then the *power of a test is considerably greater* if in place of the difference between *two* means, *one* mean calculated from the sum of the pair differences is tested.

Let A and B be the methods to be compared, $A_i - B_i = d_i$ the difference between the ... [illegible]

[illegible]

16D because of the non-independent nature of the samples

16E. Tests for two samples using the extreme range[19]

(*a*) *Two samples of the same size* $N' = N'' = N \leqq 20$

$x'_N - x'_1$ and $x''_N - x''_1$ are the extreme ranges of these samples, the test quotient is then

$$\frac{|\bar{x}' - \bar{x}''|}{x'_N - x'_1 + x''_N - x''_1} \qquad (618)$$

(for limit see page 53, bottom left-hand table)

(*b*) *Two samples of unequal size*, or of the same size but larger than in (a)

The samples are divided respectively into m' and m'' random subgroups of the same size n (cf section 14A, page 170) The sum of all the extreme ranges of these subgroups from both samples is denoted by S_R The test quotient is then

$$\frac{\bar{x}' - \bar{x}''|\sqrt{m'm''}}{S_R \times A_{m,n}}, \; (m = m' + m'', \text{for limit see page 49, for } A_{m,n} \text{ page 48}) \qquad (619)$$

17. The normally distributed population: Testing several samples

Given are n samples of sizes

$$N_1, N_2, \ldots, N_i, \ldots, N_n, \text{ where } \sum_1^n N_i = N \qquad (a)$$

The sums of the individual values x are

$$\sum_1^{N_1} x_1, \sum_1^{N_2} x_2, \ldots, \sum_1^{N_i} x_i, \ldots, \sum_1^{N_n} x_n, \text{ where } \sum_1^n \sum_1^{N_i} x_i = \sum_1^N x \qquad (b) \qquad (620)$$

The sums of the individual squares x^2 are

$$\sum_1^{N_1} x_1^2, \sum_1^{N_2} x_2^2, \ldots, \sum_1^{N_i} x_i^2, \ldots, \sum_1^{N_n} x_n^2, \text{ where } \sum_1^n \sum_1^{N_i} x_i^2 = \sum_1^N x^2 \qquad (c)$$

The sums of squares calculated in accordance with (493) are

$$S_1, S_2, \ldots, S_i, \ldots, S_n, \text{ where } \sum_1^n S_i = S \qquad (d)$$

The degrees of freedom are

$N_1 - 1, N_2 - 1, \ldots, N_i - 1, \ldots, N_n - 1$, (symbolized by $\nu_1, \nu_2, \ldots, \nu_i, \ldots, \nu_n$) where $\sum_1^n (N_i - 1) = N - n = \nu = \sum_1^n \nu_i$ (e)

The means $\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_i, \ldots, \bar{x}_n$ are defined by (491) (f)

and the variances $s_1^2, s_2^2, \ldots, s_i^2, \ldots, s_n^2$ by (492) (g)

17A. Testing variances

The hypothesis $\sigma_1^2 = \sigma_2^2 = \cdots = \sigma_i^2 = \cdots = \sigma_n^2$ is tested by m of BARTLETT's test[22].

An estimate of the common variance σ^2 is

$$s^2 = S/\nu, \text{ where } \nu_2 = N - n; \; S, \nu \text{ and } N \text{ from (620d, e and a)} \qquad ($$

The test statistic for s^2 is

$$2.3026\,(\nu \log s^2 - \sum_1^n \nu_i \log s_i^2)/k, \qquad (a)$$

s^2 from (621), ν, ν_i and s_i^2 from (620e and g)

where

$$k = 1 + \left(\sum_1^n \frac{1}{\nu_i} - \frac{1}{\nu}\right)/3(n-1), \text{ and } \nu_i \text{ from (620e)} \qquad (b) \qquad (6$$

When $\nu_1 = \nu_2 = \ldots = \nu_i = \ldots = \nu_n = \nu_0$, (622a and b) become

$$2.3026\,\nu\,[\log s^2 - (1/n)\sum_1^n \log s_i^2]/k; \text{ see (a)} \qquad (c)$$

and

$$k = 1 + (n+1)/3\nu, \text{ see (b)} \qquad (d)$$

The significance limit for the test statistics (622a) and (622c) found from the χ^2 distribution with degrees of freedom $\nu = n$ - (tables on pages 36-39, $2\alpha = 1 f_r$) If the test statistic *attains* *exceeds* the significance limit, then we may suspect that populatic with discrepant variances are among those being compared If t test statistic is *smaller* than the limit, then in accordance with (4 it can be assumed that all the populations have the same varian In this case the means can be further tested as described in sectı 17B below

17B. Testing means: Simple analysis of variance

In testing the hypothesis $\mu_1 = \mu_2 = \ldots = \mu_i = \ldots = \mu_n$ the fo lowing tabulation is first made [cf also (620)]

	Sums of squares	Degrees of freedom	Variance
Variance between the samples	S_2	$n - 1$	$s_2^2 = S_2/(n-1)$
Variances within the samples	S_1	$N - n$	$s_1^2 = S_1/(N-n)$
Total	S_T	$N - 1$	$s_T^2 = S_T/(N-1)$

(62

$$\text{where } S_2 = \sum_1^n N_i(\bar{x}_i - \bar{x})^2 = \sum_1^n \left(\sum_1^{N_i} x_i\right)^2 / N_i - \left(\sum_1^N x\right)^2 / N \qquad (a)$$

$$S_1 = S\,[\text{from (620d)}] = S_T - S_2 \qquad (b)$$

$$S_T = S_1 + S_2 = \sum_1^N x^2 - \left(\sum_1^N x\right)^2 / N \qquad (c) \qquad (62$$

$$\text{and } \bar{x} = \left(\sum_1^N x\right) / N \qquad (d)$$

In (624) a check is made by means of the two identities in (a) (b) and (c)

In (623), s_2^2 represents the dispersion of the sample means $\bar{x}$ around the common mean $\bar{x}$, s_1^2 the dispersion of the individua values around the sample means If all the samples originate fron

The t-test (Student distribution)

Applicability: When σ is unknown and the degrees of freedom of $s = N - 1 \leqq 200$

Test quotient	Significance limit		
$\dfrac{\lvert\bar{x} - \mu\rvert \sqrt{N}}{s_{N-1}}$; $N \leqq 201$	t_{N-1}, pages 32–35; $\alpha = P$, $2\alpha = 2P$	(a)	(599)
$\dfrac{(\bar{x} - \mu)^2 N}{s^2_{N-1}}$; $N \leqq 201$	t^2_{N-1}, page 42; $\alpha = \frac{1}{2}P$, $2\alpha = P$; cf. (552)	(b)	
$\dfrac{\lvert\bar{x} - \mu\rvert}{s_{N-1}}$; $N \leqq 201$	$t_{N-1}/\sqrt{N}$ = confidence factor k_2, page 43	(c)	

LORD's test based on the extreme range[19]

Applicability: Samples of size $N \leqq 20$ (a) and $N > 20$ (b)

Test quotient	Significance limit		
$\dfrac{\lvert\bar{x} - \mu\rvert}{x_N - x_1}$; $N \leqq 20$; $x_1 < x_2 < \cdots < x_N$	Page 53, middle left-hand table	(a)	(600)
$\dfrac{\lvert\bar{x} - \mu\rvert m}{[\Sigma(x_n - x_1)] A_{m,n}}$; $m \times n = N$	Page 49; $A_{m,n}$ page 48	(b)	
m = number of subgroups of size n (cf. section 14 A, page 170) in which $x_1 < x_2 < \cdots < x_n$			

The midrange test based on the extreme range[20]

Applicability: Samples of size $N \leqq 10$

Test quotient	Significance limit	
$\dfrac{\lvert x_N + x_1 - 2\mu\rvert}{x_N - x_1}$; $N \leqq 10$	Page 53, upper right-hand table	(601)

WALSH test[20, 21]

Applicability: Samples of size $4 \leqq N \leqq 14$ from *any symmetrical* population

Test quotient	Significance limit	
Page 53, lower right-hand table	Page 53, lower right-hand table	(602)

Note that while the use of (598b) and (599b) involves the squaring of $(\bar{x} - \mu)$ it obviates extracting the square root of s^2 (provided s is not required). The use of (598c) and (599c) avoids the multiplication by $\sqrt{N}$, with the further advantage that the transition from t to c in using the table on page 43 is quite 'automatic'.

(600)–(602) are straightforward *rapid tests* [especially *(601)]* in which even $\bar{x}$ does not need to be calculated. Within the tabulated range their power is practically the same as that of *(599)*. The WALSH test is suitable not only for normal but also for *any* other symmetrical distribution. In this case, the significance probability for N up to 8 is somewhat higher than that in the table. For $N > 8$ the values in the table are exact.

When a calculating machine is not available, multiplication is faster than division. In this event, the significance limit should be multiplied by the divisor of the test quotient in order to obtain the limit for the dividend.

Example 38. When t is the limit for $\dfrac{\lvert x - \mu\rvert \sqrt{N}}{s}$, then ts is the limit for $\lvert x - \mu\rvert \sqrt{N}$.

16. The normally distributed population: Comparison of two samples

In comparing two samples, the following hypotheses concerning the parameters of the original populations must be taken into consideration:

$\mu_1 = \mu_2$ (a) (603)

16A. Comparison of variances

The test quotient for the hypothesis $(\sigma_1^2 = \sigma_2^2)$ (
(570), in which the *larger of the two sample variance*
always be made the numerator. This means that renumb
of the variances with respect to the *indices of the t*
necessary when s_1^2 (from sample 1) is smaller than s
number of degrees of freedom ν_1 *in the tables on pages 40*
is always that of the numerator of (570).

s_1^2 and s_2^2 must be calculated from (492). Their de
dom are $\nu_1 = N_1 - 1$ and $\nu_2 = N_2 - 1$.

If the test quotient is *smaller* than the significance
table on pages 40 and 41, then in accordance with (
assumed that $\sigma_1^2 = \sigma_2^2$. In this case the means are
procedure given in section 16B below. If the test qu
or *exceeds* the significance limit F, then $\sigma_1^2 > \sigma_2^2$ (signi
ability $\alpha = P$) or $\sigma_1^2 \neq \sigma_2^2$ (significance probability 2
means are tested by the procedure given in section 1

16B. Comparison of means when $\sigma_1^2 = \sigma_2^2$

The following symbols are used here:

$\lvert\bar{x}_1 - \bar{x}_2\rvert = d$ and $\lvert\mu_1 - \mu_2\rvert = \boldsymbol{d}$

The estimate of the common standard deviation σ

$$s = \sqrt{\frac{S_1 + S_2}{N_1 + N_2 - 2}}; \; S_1 \text{ and } S_2 \text{ from (493)}$$

$$\nu_s = \nu_1 + \nu_2 = N_1 + N_2 - 2$$

The estimate of the standard deviation of the differe

$$s_d = s\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}; \; s \text{ from (607)}; \; \nu_{s_d} = N_1 + N_2 -$$

If σ is known, s is replaced by σ in (608). If $N_1 = 1$
$s\sqrt{1 + 1/N_2}$, $\nu = N_2 - 1$; cf. also (452) and (583c and

The test quotients for the hypotheses $(\mu_1 = \mu_2 \mid \sigma_1^2 =$

if σ is known or $\nu > 200$
d/σ_d or d/s_d; limit $\lvert c_\alpha\rvert$, page 28 (

when $\nu \leqq 200$
d/s_d; limit t_ν, pages 32–35; $\alpha = P$, $2\alpha = 2P$ (

or

d^2/s_d^2; limit t_ν^2 $[= F(1; \nu)]$, page 42; $\alpha = \frac{1}{2}P$, $2\alpha = P$ (

If the test quotient *attains* or *exceeds* the significance l
this is considered as evidence that $\mu_1 \neq \mu_2$. In this case
desirable to test the hypothesis $(\mu_1 - \mu_2 = \boldsymbol{d} \mid \sigma_1^2 = \sigma_2^2)$

The test quotients are obtained by replacing d in (609) b
$\lvert d - \boldsymbol{d}\rvert$. If the quotient exceeds the significance limit, the
this is considered as evidence that $\mu_1 - \mu_2 \neq \boldsymbol{d}$.

The confidence limits for $\boldsymbol{d}$ are

two-sided
Prob $(d - t_{\nu,\alpha} \times s_d \leqq \boldsymbol{d} \leqq d + t_{\nu,\alpha} \times s_d) = 1 - 2\alpha$ (a

one-sided with a single upper limit
Prob $(\boldsymbol{d} \leqq d + t_{\nu,\alpha} \times s_d) = 1 - \alpha$ (b)

If the test quotient in (609) is *smaller* than the significan
then it may be assumed in accordance with (474) that
Since also $\sigma_1^2 = \sigma_2^2$, the conclusion may be drawn that
samples 1 and 2 originated from the same population wit
and variance σ^2. Estimates of these parameters are

$$\bar{x} = \frac{\sum_1^{N_1} x_1 + \sum_1^{N_2} x_2}{N_1 + N_2} = \frac{N_1\bar{x}_1 + N_2\bar{x}_2}{N_1 + N_2}$$

$$s^2 = \frac{S_1 + S_2 + \dfrac{\left(\sum_1^{N_1} x_1\right)^2}{N_1} + \dfrac{\left(\sum_1^{N_2} x_2\right)^2}{N_2} - \dfrac{\left(\sum_1^{N_1} x_1 + \sum_1^{N_2} x_2\right)^2}{N_1 + N_2}}{N_1 + N_2 - 1}$$

$$\nu_1 s_1^2 + \nu_2 s_2^2 + N_1\bar{x}_1^2 + N_2\bar{x}_2^2 - \frac{(N_1\bar{x}_1 + N_2\bar{x}_2)^2}{N_1 + N_2}$$

16C. Comparison of means when $\sigma_1^2 \neq \sigma_2^2$

If σ_1 and σ_2 are known, or $N_1 + N_2 > 200$, then

$$\sigma_{\bar{d}} = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}} \text{ and } s_{\bar{d}} = \sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}} \quad \textbf{(614)}$$

and the test quotients

$$\frac{\bar{d}}{\sigma_{\bar{d}}} \text{ and } \frac{\bar{d}}{s_{\bar{d}}} \text{ or } \frac{|\bar{d} - \bar{d}|}{\sigma_{\bar{d}}} \text{ and } \frac{|\bar{d} - \bar{d}|}{s_{\bar{d}}} \quad \textbf{(615)}$$

have the same limits as **(609a)**

If σ_1 and σ_2 are unknown, then the test quotients

$$\frac{\bar{d}}{s_{\bar{d}}} \text{ and } \frac{|\bar{d} - \bar{d}|}{s_{\bar{d}}} \quad \textbf{(616)}$$

have the same limits as (609b)[53], where

$$s_{\bar{d}} = \sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}} \quad \text{(a)}$$

$$\nu = \frac{1}{k^2/\nu_1 + (1-k)^2/\nu_2} \quad \text{(b)} \quad \textbf{(617)}$$

(ν_1 and ν_2 are degrees of freedom of s_1 and s_2 respectively)

$$k = \frac{N_2 s_1^2}{N_2 s_1^2 + N_1 s_2^2} \quad \text{(c)}$$

16D. Testing pair differences

differences is tested

Let A and B be the methods to be compared, $A_i - B_i = d_i$ the difference between the results given by these methods with the object i, N the total number of objects A sample of size N of all

16D because of the non-independent nature of the samples

16E. Tests for two samples using the extreme range[19]

(a) Two samples of the same size $N' = N'' = N \leq 20$

$x'_N - x'_1$ and $x''_N - x''_1$ are the extreme ranges of these samples, the test quotient is then

$$\frac{\bar{x}' - \bar{x}''}{x'_N - x'_1 + x''_N - x''_1} \quad \textbf{(618)}$$

(for limit see page 53, bottom left-hand table)

(b) Two samples of unequal size, or of the same size but larger than in (a).

The samples are divided respectively into m' and m'' random subgroups of the same size n (cf section 14A, page 170) The sum of all the extreme ranges of these subgroups from both samples is denoted by S_R The test quotient is then

$$\frac{\bar{x}' - \bar{x}''|\sqrt{m'm''}}{S_R \times A_{m,n}}, \ (m = m' + m'', \text{ for limit see page 49, for } A_{m,n} \text{ page 48}) \quad \textbf{(619)}$$

17. The normally distributed population: Testing several samples

Given are n samples of sizes

$$N_1, N_2, \ldots, N_i, \ldots, N_n, \text{ where } \sum_1^n N_i = N \quad \text{(a)}$$

The sums of the individual values x are

$$\sum_1^{N_1} x_1, \sum_1^{N_2} x_2, \ldots, \sum_1^{N_i} x_i, \ldots, \sum_1^{N_n} x_n, \text{ where } \sum_1^n \sum_1^{N_i} x_i = \sum_1^N x \quad \text{(b)} \quad \textbf{(620)}$$

The sums of the individual squares x^2 are

$$\sum_1^{N_1} x_1^2, \sum_1^{N_2} x_2^2, \ldots, \sum_1^{N_i} x_i^2, \ldots, \sum_1^{N_n} x_n^2, \text{ where } \sum_1^n \sum_1^{N_i} x_i^2 = \sum_1^N x^2 \quad \text{(c)}$$

The sums of squares calculated in accordance with **(493)** are

$$S_1, S_2, \ldots, S_i, \ldots, S_n, \text{ where } \sum_1^n S_i = S \quad \text{(d)}$$

The degrees of freedom are

$$N_1 - 1, N_2 - 1, \ldots, N_i - 1, \ldots, N_n - 1,$$

(symbolized by $\nu_1, \nu_2, \ldots, \nu_i, \ldots, \nu_n$) (e) **(620)**

$$\text{where } \sum_1^n (N_i - 1) = N - n = \nu = \sum_1^n \nu_i$$

The means $\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_i, \ldots, \bar{x}_n$ are defined by **(491)** (f)

and the variances $s_1^2, s_2^2, \ldots, s_i^2, \ldots, s_n^2$ by **(492)** (g)

17A. Testing variances

The hypothesis $\sigma_1^2 = \sigma_2^2 = \cdots = \sigma_i^2 = \cdots = \sigma_n^2$ is tested by means of BARTLETT's test[22].

An estimate of the common variance σ^2 is

$$s^2 = S/\nu, \text{ where } \nu_s = N - n \quad S, \nu \text{ and } N \text{ from (620d, e and a)} \quad \textbf{(621)}$$

The test statistic for s^2 is

$$2.3026\,(\nu \log s^2 - \sum_1^n \nu_i \log s_i^2)/k, \quad \text{(a)}$$

s^2 from **(621)**, ν, ν_i and s_i^2 from **(620e and g)**

where

$$k = 1 + \left(\sum_1^n \frac{1}{\nu_i} - \frac{1}{\nu}\right)/3(n-1), \ \nu \text{ and } \nu_i \text{ from (620e)} \quad \text{(b)} \quad \textbf{(622)}$$

When $\nu_1 = \nu_2 = \ldots = \nu_i = \ldots = \nu_n = \nu_0$, **(622a and b)** become

$$2.3026\,\nu\,[\log s^2 - (1/n) \sum_1^n \log s_i^2]/k, \text{ see (a)} \quad \text{(c)}$$

and

$$k = 1 + (n+1)/3\nu, \text{ see (b)} \quad \text{(d)}$$

The significance limit for the test statistics **(622a)** and **(622c)** is found from the χ^2 distribution with degrees of freedom $\nu = n - 1$

17B below

17B. Testing means: Simple analysis of variance

In testing the hypothesis $\mu_1 = \mu_2 = \ldots = \mu_i = \ldots = \mu_n$ the following tabulation is first made [cf also **(620)**]:

	Sums of squares	Degrees of freedom	Variance
Variance between the samples	S_2	$n-1$	$s_2^2 = S_2/(n-1)$
Variances within the samples ...	S_1	$N-n$	$s_1^2 = S_1/(N-n)$
Total	S_T	$N-1$	$s_T^2 = S_T/(N-1)$

(623)

$$\text{where } S_2 = \sum_1^n N_i(\bar{x}_i - \bar{x})^2 = \sum_1^n \left(\sum_1^{N_i} x_i\right)^2 / N_i - \left(\sum_1^N x\right)^2 / N \quad \text{(a)}$$

$$S_1 = S \,[\text{from (620d)}] = S_T - S_2 \quad \text{(b)} \quad \textbf{(624)}$$

$$S_T = S_1 + S_2 = \sum_1^N x^2 - \left(\sum_1^N x\right)^2 / N \quad \text{(c)}$$

$$\text{and } \bar{x} = \left(\sum_1^N x\right) / N \quad \text{(d)}$$

In **(624)** a check *is* made by means of the two identities in (a), (b) and (c)

In **(623)**, s_2^2 *represents the* dispersion *of the sample means* $\bar{x}_i$ around the common mean $\bar{x}$, s_1^2 the dispersion of the individual values around the sample means If all the samples originate from

the same population, so that $\mu_1 = \mu_2 = \cdots = \mu_i = \cdots = \mu_n = \mu$ (the hypothesis in the light of which the variances have been tested), then the variances s_2^2 and s_1^2 should be approximately of the same magnitude. If they are not, then among the samples are some with discrepant means, in which case s_2^2 must be greater than s_1^2. The necessity of carrying out the appropriate F test is thus avoided when $s_2^2 \lesssim s_1^2$.

The test quotient is s_2^2/s_1^2, limit F, pages 40–41; $\alpha = P$ with $s_2^2 > s_1^2$. **(625)**

If the test quotient is smaller than the significance limit, then in accordance with **(474)** it can be assumed that all the samples originate from the same population. The estimates of their mean μ and variance σ^2 are

$$\bar{x} = \textbf{(624d)};\ s^2 = \textbf{(621)},\ \text{with } \nu = N - n \qquad \textbf{(626)}$$

with confidence and tolerance intervals constructed as described in **(580)–(584)**.

If the test quotient attains or exceeds the significance limit F, then among the means there must be some of discrepant magnitude. Various methods of analysing this situation have been proposed[23]. Here that of DUNCAN[23] will be used.

The method is dependent on *all samples having the same size* N_0. The standard deviation of a mean $\bar{x}_i$ is first calculated

$$s_{\bar{x}_i} = \sqrt{s^2/N_0};\ s^2 \text{ from } \textbf{(621)} \qquad \textbf{(627)}$$

$$\nu_{s\bar{x}_i} = N - n$$

The means $\bar{x}_i$ are now ranked

$$\left.\begin{array}{l}\bar{x}_1 < \bar{x}_2 < \cdots < \bar{x}_i < \cdots < \bar{x}_n; \\ 1, 2, \ldots, i, \ldots, n = \text{ranks } O\end{array}\right\} \qquad \textbf{(628)}$$

and the n extreme ranges W_i corresponding to the degrees of freedom $\nu_{s\bar{x}_i}$ and the ranks $O = 2, 3, \ldots, n$ looked for in the table on page 50. Multiplication of these by the standard deviation of a mean $s_{\bar{x}_i}$ [cf. **(627)**] gives the extreme ranges of the means $W_{\bar{x}_i}$. Subtraction of these from the means $\bar{x}_i$ gives the 'localized extreme ranges' $\bar{x}_i - W_{\bar{x}_i}$. The following conclusions can now be drawn:

The means falling in a 'localized extreme range' $\bar{x}_i - W_{\bar{x}_i}$ cannot be distinguished from each other significantly. **(629)**

The means not distinguishable in **(629)** are underscored in the order of **(628)**, with the result that

two means *not* underscored with a common line differ from one another significantly (significance probability α of the table). **(630)**

Example 39. Given are 7 samples with the means $\bar{x}_i$ shown below. $N_0 = 5$, $N = 35$, $s_\nu = 0.099$, $\nu_s = 28$. Significance probability $= 0.05$.

From **(627)** the estimated standard deviation of a mean is $s_{\bar{x}_i} = \sqrt{0.099/5} \approx 0.1407$. The extreme ranges W_i and $W_{\bar{x}_i} = W_i \times s_{\bar{x}_i}$ are given in the table below. The differences $\bar{x}_i - W_{\bar{x}_i}$ are then calculated up to the point where the corresponding underscoring reaches or passes the lowest mean.

i	1	2	3	4	5	6	7
$\bar{x}_i$	1.34	1.36	1.48	1.62	1.74	1.88	2.04
W_i		2.90	3.04	3.13	3.20	3.26	3.30
$W_{\bar{x}_i}$		0.408	0.428	0.440	0.450	0.459	0.464
$\bar{x}_i - W_{\bar{x}_i}$					1.290	1.421	1.576
(629)	1.34	1.36	1.48	1.62	1.74	1.88	2.04

The final result is given by **(630)**: 2.04 > 1.34 to 1.48; 1.88 > 1.34 to 1.36.

18. The normally distributed population: Regressions of the first kind

Discussion will be limited here to *linear* regression functions. The functional relationships between two or more variables are often more or less obscured by random influences. Thus the effect of a dose of a drug, for example, will change in a certain way [as the] dose is increased. The effect will never be an exact function [of the] dosage, however, and even in the same subject will fluc[tuate] around a curve – the *regression function* – in a random manner. [By] statistical methods it is possible to estimate the parameters [of the] regression function and the required variances.

Although in the above example *the dose is not a ra[ndom]* variable, the effect it brings about is a random variable. In thi[s case] the regression is one of the *first kind*. In cases where *both* vari[ables] are random variables the regression is one of the *second ki[nd]*. [A] regression of the second kind can be treated as a regression o[f the] first kind when the range of variation of the dependent variab[le as] well as the points at which it is measured are arbitrarily de[cided] beforehand.

In regressions of the first kind there is a *single* regression [line,] that of y on x, which is used for calculations in both directi[ons,] from y to x as well as from x to y. Cf. also section 19, page [...]

18A. Estimation of the parameters of the regression line [...] [cf. also (298)–(311)]

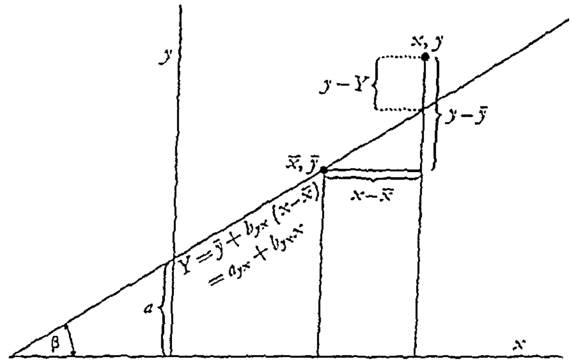


Fig. 35. Linear regression, ungrouped sample.

Ungrouped samples, two variables

Given are n pairs of observations x, y. x is the *independent, n[on-]random* variable, y the *dependent, random* variable.

Estimate Y of the regression line $\mathbf{Y}$

$$\left.\begin{array}{ll}Y = \bar{y} + b_{yx}(x - \bar{x}) & \text{(a)} \\ \quad = a_{yx} + b_{yx}x & \text{(b)}\end{array}\right\} \quad \textbf{(6[31])}$$

where $a_{yx} = \bar{y} - b_{yx}\bar{x}$, with $\bar{y}$ and $\bar{x}$ calculated from **(491)**, b_{yx} fro[m] **(632)**.

Estimate b_{yx} of the regression coefficient $\boldsymbol{b}_{yx}$

$$b_{yx} = \frac{s_{xy}}{s_x^2} = \frac{S_{xy}}{S_x} \qquad \textbf{(63[2])}$$

with s_x^2 and S_x from **(492)** and **(493)**. For s_{xy} see **(633)**. b_{yx} is t[he] tangent of the angle of inclination β_{yx} of the regression line [...] Cf. also **(299)**.

Estimate s_{xy} of the covariance σ_{xy}

$$s_{xy} = \frac{\Sigma(x - \bar{x})(y - \bar{y})}{n - 1} = \frac{S_{xy}}{n - 1} \qquad \textbf{(63[3])}$$

For S_{xy} see **(634)**.

The calculation of S_{xy} is facilitated by the use of the followin[g] sums:

$$\left.\begin{array}{ll}S_{xy} = \Sigma(x - \bar{x})(y - \bar{y}) & \text{(a)} \\ \quad = \Sigma xy - \bar{x}\Sigma y & \text{(b)} \\ \quad = \Sigma xy - \bar{y}\Sigma x & \text{(c)} \\ \quad = \Sigma xy - \Sigma x \Sigma y/n & \text{(d)} \\ \quad [= s_{xy}(n - 1)] & \text{(e)}\end{array}\right\} \quad \textbf{(634)}$$

nate $s^2_{y \cdot x}$ of the residual variance $\sigma^2_{y \cdot x}$

$$
\left.\begin{aligned}
{}_x &= \frac{\Sigma (Y-y)^2}{n-2} = \frac{S_{y \cdot x}}{n-2} && \text{(a)}\\
&= s^2_y (1 - r^2)\frac{n-1}{n-2} && \text{(b)}
\end{aligned}\right\} \quad (635)
$$

$S_{y \cdot x}$ and r^2 see (636) and (704)

${}_x$ is the variance of y when x is fixed. It is *smaller* than the vari- σ^2_y. In very rare cases (with very small correlation or regres- coefficients) we can have

$$(1 - r^2)\frac{n-1}{n-2} > 1, \text{ in which case } s^2_{y \cdot x} > s^2_y$$

$$
\left.\begin{aligned}
S_{y \cdot x} &= S_y - b_{yx} S_{xy} && \text{(a)}\\
&= S_y - b^2_{yx} S_x && \text{(b)}\\
&= S_y (1 - r^2) && \text{(c)}
\end{aligned}\right\} \quad (636)
$$

and S_x from (439), S_{xy} from (634), b_{yx} from (632); r^2 from (704) e remarks above on (635b) apply also to (636c).

stimate $s^2_{b_{yx}}$ of the variance $\sigma^2_{b_{yx}}$

$$
\left.\begin{aligned}
s^2_{b_{yx}} &= s^2_{y \cdot x}/S_x && \text{(a)}\\
&= (s^2_y/s^2_x) \times \frac{1-r^2}{n-2} = (S_y/S_x) \times \frac{1-r^2}{n-2} && \text{(b)}
\end{aligned}\right\} \quad (637)
$$

and s^2_x from (492); S_y and S_x from (493); $s^2_{y \cdot x}$ from (635); r^2 from 04). The remarks above on (635b) apply also to (637b)

stimate $s^2_{Y|x}$ of the variance $\sigma^2_{Y|x}$ about the regression line Y for given value of x

$$
\left.\begin{aligned}
s^2_{Y \cdot x} &= s^2_{y \cdot x}\,[1/n + (x-\bar{x})^2/S_x] && \text{(a)}\\
&= s^2_{b_{yx}}\,[S_x/n + (x-\bar{x})^2] && \text{(b)}
\end{aligned}\right\} \quad \nu = n-2 \quad (638)
$$

${}_x$ from (493), $s^2_{y \cdot x}$ from (635), $s^2_{b_{yx}}$ from (637)

Special cases of (638) are

stimate $s^2_{\bar{y}}$ of the variance $\sigma^2_{\bar{y}}$ of the mean $\bar{y}$

$$s^2_{\bar{y}} = s^2_{y \cdot x}/n, \quad \nu = n-2 \qquad (639)$$

stimate $s^2_{a_{yx}}$ of the variance $\sigma^2_{a_{yx}}$ of the intercept a

$$
\left.\begin{aligned}
s^2_{a_{yx}} &= s^2_{y \cdot x}\,(1/n + \bar{x}^2/S_x) && \text{(a)}\\
&= s^2_{b_{yx}}\,(\Sigma x^2)/n && \text{(b)}
\end{aligned}\right\} \quad \nu = n-2 \quad (640)
$$

${}_{b_{yx}}$ from (637).

Example 40 Given is the sample

x	y	x	y	x	y
5.8	2.19	7.0	4.62	8.2	6.58
6.2	3.27	7.4	5.32	8.6	7.41
6.6	3.79	7.8	5.85	9.0	8.29

The y values in this example correspond to the empirical probits of example 31 in section 11F, page 163

It follows that

$\bar{x}$ = 7.4 from (491)

S_x = 9.6 from (493)

$\bar{y}$ = 47.32/9 = 5.257 from (491)

S_y = 280.651 − 248.798 = 31.853 from (493)

s^2_y = $S_y/8$ = 3.981625, s_y = 1.9954 from (492b)

S_{xy} = 367.620 − 350.168 = 17.452 from (634)

b_{yx} = 17.452/9.6 = 1.817916 from (632)

$S_{y \cdot x}$ = 31.8530 − 31.7263 = 0.1267 from (636a or b)

$s^2_{y \cdot x}$ = 0.1267/7 = 0.0181, $s_{y \cdot x}$ = 0.13454 from (635a)

$s^2_{b_{yx}}$ = 0.0181/9.6 = 0.00188542, $s_{b_{yx}}$ = 0.043421 from (637a)

$s^2_{\bar{y}}$ = 0.0181/9 = 0.00201, $s_{\bar{y}}$ = 0.044843 from (639)

$$s^2_{a_{yx}} = 0.0181\left(0.1 + \frac{(7.4)^2}{9.6}\right) = 0.105257, \; s_{a_{yx}} = 0.32443$$
from (640a)

Y = 5.257 + 1.817916 (x − 7.4) from (631a)
= − 8.1948 + 1.8179x from (631b)

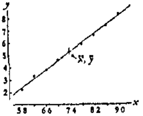


Fig 36 Probit line of example 40

A comparison of Figure 36 with Figure 30 (page 164) shows that

Grouped samples, two variables

Given are 1, 2, ..., i, ..., k points of measurement (columns) x_i with $m_1, m_2, \ldots, m_i, \ldots, m_k$ observations y_{ij}. x is the *independent, non-random* variable, y the *dependent, random* variable.

(641)

x	1	2	... i	... k	
y	11	21	i1	.. k1	
	12	22	i2	.. k2	
	1j	2j	ij	kj	
	1 m_1	2 m_2	$i\,m_i$	$k\,m_k$	
	$\sum_{j=1}^{m_1} y_{1j}$	$\sum_{j=1}^{m_2} y_{2j}$	$\sum_{j=1}^{m_i} y_{ij}$	$\sum_{j=1}^{m_k} y_{kj}$	
	Overall sum Σy, column sum Σy_i				(a, b)
	$\frac{(\sum_{j=1}^{m_1} y_{1j})^2}{m_1}$	$\frac{(\sum_{j=1}^{m_2} y_{2j})^2}{m_2}$	$\frac{(\sum_{j=1}^{m_i} y_{ij})^2}{m_i}$	$\frac{(\sum_{j=1}^{m_k} y_{kj})^2}{m_k}$	
	Overall sum $\Sigma (\Sigma y_i)^2/m_i$				(c)
xy	$x_1 \sum_{j=1}^{m_1} y_{1j}$	$x_2 \sum_{j=1}^{m_2} y_{2j}$	.. $x_i \sum_{j=1}^{m_i} y_{ij}$	... $x_k \sum_{j=1}^{m_k} y_{kj}$	
	Overall sum Σxy				(d)
y^2	$(11)^2$	$(21)^2$	... $(i1)^2$	... $(k1)^2$	
	$(12)^2$	$(22)^2$	... $(i2)^2$	... $(k2)^2$	
	$(1j)^2$	$(2j)^2$	... $(ij)^2$	... $(kj)^2$	
	$(1\,m_1)^2$	$(2\,m_2)^2$	... $(i\,m_i)^2$	... $(k\,m_k)^2$	
	$\sum_{j=1}^{m_1} y^2_{1j}$	$\sum_{j=1}^{m_2} y^2_{2j}$	... $\sum_{j=1}^{m_i} y^2_{ij}$	... $\sum_{j=1}^{m_k} y^2_{kj}$	
	Overall sum Σy^2, column sum Σy^2_i				(e; f)
x	$m_1 x_1$	$m_2 x_2$	.. $m_i x_i$	... $m_k x_k$	
	Overall sum Σx				(g)
	$m_1 x^2_1$	$m_2 x^2_2$	... $m_i x^2_i$	... $m_k x^2_k$	
	Overall sum Σx^2				(h)
$n = m_1$	$+ m_2 +$	$\cdots + m_i + \cdots$	$+ m_k$		(i)

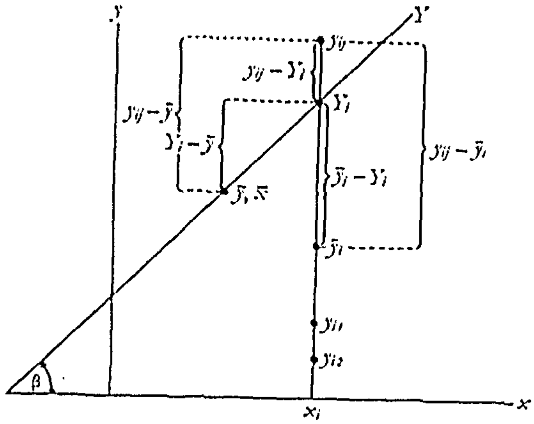


Fig. 37. Linear regression, grouped sample.

(641) allows the following to be calculated:

Column means

$$\bar{y}_i = (\Sigma y_i)/m_i = (641\,\mathrm{b})/m_i \tag{642}$$

Sums of the squares of the deviations of the individual column values from the column means

$$Sy_i = \Sigma y_i^2 - (\Sigma y_i)^2/m_i = (641\,\mathrm{f}) - (641\,\mathrm{b})^2/m_i \tag{643}$$

Overall mean

$$\bar{y} = (\Sigma y)/n = (641\,\mathrm{a})/(641\,\mathrm{i}) \tag{644}$$

Mean of the independent variables

$$\bar{x} = (\Sigma x)/n = (641\,\mathrm{g})/(641\,\mathrm{i}) \tag{645}$$

Sums of the squares of the deviations of x from $\bar{x}$

$$S_x = \Sigma x^2 - (\Sigma x)^2/n = (641\,\mathrm{h}) - (641\,\mathrm{g})^2/(641\,\mathrm{i}) \tag{646}$$

Sums of products

$$S_{xy} = \Sigma xy - \Sigma x \Sigma y/n = (641\,\mathrm{d}) - (641\,\mathrm{g})\,(641\,\mathrm{a})/(641\,\mathrm{i}) \tag{647}$$

Regression coefficient

$$b_{yx} = S_{xy}/S_x = (647)/(646) \tag{648}$$

Sums of the squares for variation within columns

$$\left.\begin{aligned} S_1 &= \sum_1^k Sy_i = \sum_1^k (643) \\ &\left[= \sum_{i=1}^k \sum_{j=1}^{m_i} (y_{ij}-\bar{y}_i)^2\right] \end{aligned}\right\} \tag{649}$$

Sums of the squares of the deviations of the column means from the regression line Y

$$\left.\begin{aligned} S_2 &= \Sigma(\Sigma y_i)^2/m_i - (\Sigma y)^2/n - S_3 \\ &= (641\,\mathrm{c}) - (641\,\mathrm{a})^2/(641\,\mathrm{i}) - (651) \\ &\left[= \sum_{i=1}^k m_i(\bar{y}_i - Y_i)^2\right] \end{aligned}\right\} \tag{650}$$

S_3 from (651)

Sums of the squares of the deviations of the regression line from the overall mean

$$\left.\begin{aligned} S_3 &= b_{yx}S_{xy} = b_{yx}^2 S_x = S_{xy}^2/S_x = (648)(647) = (648)^2(646) \\ &\left[= \sum_{i=1}^k m_i(Y_i - \bar{y})^2\right] \end{aligned}\right\} \tag{651}$$

Sums of the squares of the deviations of the individual values from the overall mean

$$\left.\begin{aligned} S_y &= \Sigma y^2 - (\Sigma y)^2/n = (641\,\mathrm{e}) - (641\,\mathrm{a})^2/(641\,\mathrm{i}) \\ &[= \Sigma(y_{ij}-\bar{y})^2] \end{aligned}\right\} \tag{652}$$

Check:

$$S_1 + S_2 + S_3 = S_y \tag{653}$$

Sums of the squares of the residual variations

$$S_{y\cdot x} = S_1 + S_2 = S_y - S_3 = (649) + (650) = (652) - (651) \tag{654}$$

Estimated variances

$$s_1^2 = S_1/(n-k) = (649)/(n-k);\ \nu = n-k \tag{655}$$

$$s_2^2 = S_2/(k-2) = (650)/(k-2);\ \nu = k-2 \tag{656}$$

$$s_3^2 = S_3 = (651);\ \nu = 1 \tag{657}$$

$$s_y^2 = S_y/(n-1) = (652)/(n-1);\ \nu = n-1 \tag{658}$$

$$s_{y\cdot x}^2 = S_{y\cdot x}/(n-2) = (654)/(n-2);\ \nu = n-2 \tag{659}$$

The equation of the regression line Y and the estimated variances $s_{b_{yx}}^2, s_{\bar{Y}|x}^2, s_{\bar{y}}^2, s_{a_{yx}}^2$ are obtained from (631), (637), (638), (639) and (640) by replacing b_{yx} by (648), $s_{y\cdot x}^2$ by (659) and S_x by (646).

Example 41. Given is the sample

x	7	8	9
y	1.0 1.4 2.0 2.2	2.0 2.5 2.8 3.1 3.7 4.0	2.9 3.2 3.4 3.9 4.4
$\bar{y}_i$	6.6/4 = 1.65	18.1/6 ≈ 3.01$\dot{6}$	17.8/5 = 3.56 from (642)
Sy_i	11.8 − 10.89 = 0.91	57.39 = 54.601$\dot{6}$ = 2.788$\dot{3}$	64.78 − 63.368 = 1.412 from (643)

n = 15 from (641 i)
$\bar{y}$ = 42.5/15 = 2.8$\dot{3}$ from (644); $\bar{x}$ = (28 + 48 + 45)/15 = 8.0$\dot{6}$ from (645)
S_x = (196 + 384 + 405) − (28 + 48 + 45)²/15 = 8.9$\dot{3}$ from (646)
S_{xy} = 46.2 + 144.8 + 160.2 − 8.06 × 42.5 = 8.3$\dot{6}$ from (647)
b_{yx} = 8.3$\dot{6}$/8.9$\dot{3}$ ≈ 0.936567164 from (648)
S_1 = 0.91 + 2.788$\dot{3}$ + 1.412 = 5.110$\dot{3}$ from (649)
S_2 = 6.6²/4 + 18.1²/6 + 17.8²/5 − 42.5²/15 − S_3 = 0.607054728 from (650)
S_3 = 0.936567164 × 8.3$\dot{6}$ = 7.835945272 from (651)
S_y = 133.97 − 42.5²/15 = 13.55$\dot{3}$ from (652)
Check: 5.110$\dot{3}$ + 0.607054728 + 7.835945272 = 13.55$\dot{3}$ from (653)
$S_{x\cdot y}$ = 5.110$\dot{3}$ + 0.607055 = 5.717388 from (654)
$s_{y\cdot x}^2$ = 5.717388/13 = 0.439799; $s_{y\cdot x}$ = 0.663173 from (659)
$s_{b_{yx}}^2$ = 0.439799/8.9$\dot{3}$ = 0.0492312; $s_{b_{yx}}$ = 0.221881 from (637a)
Y = 2.8$\dot{3}$ + 0.936567(x − 8.0$\dot{6}$) = −4.72164 + 0.936567 x from (631)
s_1^2 = S_1/12 = 0.425861 from (655); s_2^2 = S_2/1 from (656); s_3^2 = S_3 from (657)

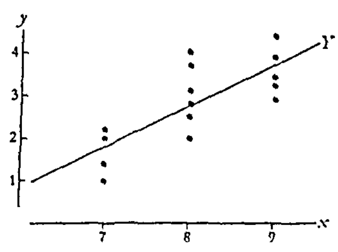


Fig. 38. Regression line of example 41.

18B. Testing the linearity of the regression function

With *ungrouped* samples, general departure from linearity of the regression function can be tested only by eye. The deviations $Y_i - y_i$ should give an impression of randomness and not show any systematic trend (cf. for example Fig. 29 [systematic deviations] with Fig. 30, right [apparently random deviations], on page 164).

With *grouped* samples an exact test is possible, namely by comparing the variance of the column means about the regression line with the variance within the columns.

Test quotient:

$$s_2^2/s_1^2 = (656)/(655);\ \text{significance limit } F\left\{\begin{aligned}\nu_1 &= k-2\\ \nu_2 &= n-k\end{aligned}\right\} \tag{660}$$

($2P = 2\alpha$, table on pages 40 and 41 [ν_1 of the table = ν_2 of the test quotient])

If the test quotient *attains* or *exceeds* the significance limit, then the regression function is quite possibly nonlinear (significance probability $2\alpha = 2P$). If the test quotient is *smaller* than the signifi-

.Testing the regression coefficient against zero

f the linearity of the regression function is not disproved by the

st statistics

$$\left. \begin{array}{l} b_{yx}/s_{b_{yx}};\ \text{significance limit } t,\ 2P = 2\alpha, \\ \nu = n-2, \text{ pages 32-35} \end{array} \right\} \quad (661)$$

from (632) or (648), $s_{b_{yx}} = \sqrt{(637a)}$

$$\left. \begin{array}{ll} b_{yx}^2/s_{b_{yx}}^2 = b\,S_{xy}/s_{y\,x}^2;\ \text{significance limit } t^2, & \text{(a)} \\ P = 2\alpha,\ \nu = n-2, \text{ page 42} & \\ b\,S_{xy} - t_{2\alpha}^2 s_{y\,x}^2,\ \text{significance limit null},\ t^2 \text{ as in (662a)} & \text{(b)} \end{array} \right\} \quad (662)$$

ith ungrouped samples, $b\,S_{xy}$ is obtained from (632) and (634), ith grouped samples from (651) $s_{y\,x}^2$ is obtained from (635) or 59)]

if the correlation coefficient r has been calculated (cf section 9A, page 179), then

$$\text{when } r = 0, \text{ it follows that } b_{yx} \text{ (and } b_{xy}) = 0 \quad (663)$$

nd vice versa The hypothesis $b_{yx} = 0$ can be tested using r Significance limit for $|r|$, see page 61, $\nu = n-2$

If any of the test statistics in (661)–(663) attains or exceeds the corresponding significance limit, then b_{yx} differs significantly from zero The above tests are special cases of (664a) for $b_{yx} = 0$

18D. Testing the difference between estimate and hypothetical value

Test quotients (absolute values should be used)

$$\left. \begin{array}{lll} (b_{yx} - \boldsymbol{b}_{yx})/s_{b_{yx}}, & \nu = n-2,\ s_{b_{yx}} = \sqrt{(637)} & \text{(a)} \\ (Y\,x - \boldsymbol{Y}\,x)/s_{Y|x}, & \nu = n-2,\ s_{Y|x} = \sqrt{(638)} & \text{(b)} \\ (\bar{y} - \mu_y)/s_{\bar{y}}, & \nu = n-2,\ s_{\bar{y}} = \sqrt{(639)} & \text{(c)} \\ (a_{yx} - \boldsymbol{a}_{yx})/s_{a_{yx}}, & \nu = n-2,\ s_{a_{yx}} = \sqrt{(640)} & \text{(d)} \end{array} \right\} \quad (664)$$

Example 43 [of (664a)] Comparison between the regression

$$\frac{1\,8179 - 1\,7123}{0\,04342} = 2\,432,\ \nu = 7$$

The corresponding significance limit $t_{5\%,\,\nu=7}$, page 32, is 2 3646 The two regression coefficients, and therefore the regression lines, thus differ significantly

18E. Confidence and tolerance limits

Here only the formulae for the two-sided limits will be given, and these in the form of 'estimate $\pm\,G$' (estimate minus G = lower limit, estimate plus G = upper limit). The parameters are intended to be included between these two limits

Confidence limits

$$\text{For } \boldsymbol{b}_{yx}: \quad \left. \begin{array}{l} b_{yx} \pm t_{2\alpha} s_{b_{yx}};\ \nu = n-2 \leq 200 \\ b_{yx} \pm |t_\alpha|\, s_{b_{yx}};\ \nu = n-2 > 200 \end{array} \right\} s_{b_{yx}} = \sqrt{(637)} \quad (665)$$

For $\boldsymbol{Y}\,|\,x$:

$$\left. \begin{array}{r} \bar{y} + b_{yx}(x - \bar{x}) \pm t_{2\alpha} s_{Y|x};\ \nu = n-2 \leq 200 \\ \pm |t_\alpha|\, s_{Y|x};\ \nu = n-2 > 200 \end{array} \right\} s_{Y|x} = \sqrt{(638)} \quad (666)$$

$$\text{For } \mu_y: \quad \left. \begin{array}{ll} \bar{y} \pm t_{2\alpha} s_{\bar{y}}; & \nu = n-2 \leq 200 \\ \bar{y} \pm |t_\alpha|\, s_{\bar{y}}, & \nu = n-2 > 200 \end{array} \right\} s_{\bar{y}} = \sqrt{(639)} \quad (667)$$

$$\text{For } \boldsymbol{a}_{yx}: \quad \left. \begin{array}{ll} a_{yx} \pm t_{2\alpha}\, s_{a_{yx}}, & \nu = n-2 \leq 200 \\ a_{yx} \pm |t_\alpha|\, s_{a_{yx}}, & \nu = n-2 > 200 \end{array} \right\} s_{a_{yx}} = \sqrt{(640)} \quad (668)$$

(666) is a hyperbola (cf Fig 39)

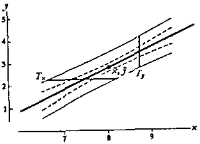


Fig 39 Confidence and tolerance limits for the regression of Figure 38 - - - Confidence limits for $\boldsymbol{Y}$ ——— Tolerance limits for $\boldsymbol{Y}$ T_y Tolerance interval for $Y\,|\,x$ T_x Tolerance interval for $X\,|\,y$

Tolerance limits for $\boldsymbol{Y}\,|\,x$

$$\left. \begin{array}{l} = \bar{y} + b_{yx}(x - \bar{x}) \pm t_{2\alpha} s_T,\ \nu_t = n-2, \\ b_{yx} \text{ from (632) or (648)} \end{array} \right\} \quad (669)$$

where

$$\left. \begin{array}{ll} s_T = s_{y\,x}\sqrt{1 + 1/n + (x-\bar{x})^2/S_x},\ \nu = n-2 & \text{(a)} \\ \quad = s_{b_{yx}}\sqrt{(1 + 1/n)\,S_x + (x-\bar{x})^2},\ \nu = n-2 & \text{(b)} \end{array} \right\} \quad (670)$$

S_x from (493) or (646), $s_{y\,x} = \sqrt{(635)}$ or $\sqrt{(659)}$; $s_{b_{yx}} = \sqrt{(637a)}$, $\bar{x}$ = (493) or (645)

18F Estimation of x when y is given

$$x\,|\,y = \bar{x} + \frac{y - \bar{y}}{b_{yx}} \quad (671)$$

Confidence limits for the expected value of x, given y [solution from (666) for x]

$$\left. \begin{array}{l} \bar{x} + \dfrac{y - \bar{y}}{b_{yx}(1 - k^2)} \pm \\ \pm \dfrac{k}{b_{yx}(1 - k^2)}\sqrt{(1/n)\,b_{yx}^2 (1 - k^2)\,S_x + (y - \bar{y})^2} \end{array} \right\} \quad (672)$$

where for ungrouped samples b_{yx} and S_x are obtained from (632) and (493), for grouped samples from (648) and (646)

$$k^2 = \frac{t_{2\alpha}^2 s_{b_{yx}}^2}{b_{yx}^2},\ \nu_t = n-2 \quad (673)$$

where $s_{b_{yx}}^2 = (637)$

If $k^2 \leq 0\,05$, then $1 - k^2$ can be taken as 1 in (672)

Tolerance limits for $x\,|\,y$ [solution from (669) for x]

$$\left. \begin{array}{l} \text{(672) is used, but with } (1 + 1/n) \text{ in place of } 1/n \text{ in the term} \\ \text{under the root} \end{array} \right\} \quad (674)$$

Example 44 In example 40, it is required to calculate x for $y = 5$ and the corresponding confidence and tolerance limits $x\,|\,y = 5$

$$x = 7\,4 + \frac{5 - 5\,257}{1\,817916} = 7{,}258\,2 \text{ from (671)}$$

Confidence limits: k^2 is first calculated from **(673)**, giving

$$k^2 = \frac{2.3646^2 \times 0.00188542}{1.817916} = 0.003190;\ k = 0.05648$$

k^2 is less than 0.05, so that $1 - k^2$ can be taken as 1 in **(672)**. For purposes of comparison, however, **(672)** is calculated with both values:

	Confidence limits	Tolerance limits
$1 - k^2 = 1$	7.2582 ± 0.0589 $= 7.1993$ to 7.3171	7.2582 ± 0.5534 $= 6.7048$ to 7.8116
$1 - k^2 = 0.996810$	7.2577 ± 0.0590 $= 7.1987$ to 7.3167 from **(672)**	7.2577 ± 0.5545 $= 6.7032$ to 7.8122 from **(674)**

18G. Comparison of two regression lines of the first kind

Given are the following ungrouped and grouped samples

$(x, y)_1$ with n_1	and $(x, y)_2$ and n_2	pairs of observations
$\bar{x}_1$	and $\bar{x}_2$	from **(491)** or **(645)**
$\bar{y}_1$	and $\bar{y}_2$	from **(491)** or **(644)**
S_{x_1}	and S_{x_2}	from **(493)** or **(646)**
S_{y_1}	and S_{y_2}	from **(493)** or **(652)**
$(S_{xy})_1$	and $(S_{xy})_2$	from **(634)** or **(647)**
$(S_{y\cdot x})_1$	and $(S_{y\cdot x})_2$	from **(636)** or **(654)**
$(s^2_{y\cdot x})_1$	and $(s^2_{y\cdot x})_2$	from **(635)** or **(659)**
$(b_{yx})_1 = b_1$	and $(b_{yx})_2 = b_2$	from **(632)** or **(648)**
Y_1	and Y_2	from **(631)**

In analogy with section 16 (page 172), the following hypotheses must be considered in comparing two linear regressions:

$$(\sigma^2_{y\cdot x})_1 = (\sigma^2_{y\cdot x})_2 \begin{cases} \boldsymbol{b}_1 = \boldsymbol{b}_2 \begin{cases} \boldsymbol{Y}_1 = \boldsymbol{Y}_2 \\ \boldsymbol{Y}_1 \neq \boldsymbol{Y}_2 \end{cases} \text{(a)} \begin{cases} \text{(a c)} \\ \text{(a d)} \end{cases} \\ \boldsymbol{b}_1 \neq \boldsymbol{b}_2 \quad \text{(b)} \end{cases} \qquad \textbf{(675)}$$

$$(\sigma^2_{y\cdot x})_1 \neq (\sigma^2_{y\cdot x})_2 \begin{cases} \boldsymbol{b}_1 = \boldsymbol{b}_2 \begin{cases} \boldsymbol{Y}_1 = \boldsymbol{Y}_2 \\ \boldsymbol{Y}_1 \neq \boldsymbol{Y}_2 \end{cases} \text{(a)} \begin{cases} \text{(a c)} \\ \text{(a d)} \end{cases} \\ \boldsymbol{b}_1 \neq \boldsymbol{b}_2 \quad \text{(b)} \end{cases} \qquad \textbf{(676)}$$

The hypothesis $(\sigma^2_{y\cdot x})_1 = (\sigma^2_{y\cdot x})_2$ is tested by means of the quotient

$$\frac{(s^2_{y\cdot x})_1}{(s^2_{y\cdot x})_2};\ \begin{Bmatrix} \text{significance limit } F; \\ 2P = 2\alpha; \end{Bmatrix} \begin{Bmatrix} \nu_1 = n_1 - 2 \\ \nu_2 = n_2 - 2 \end{Bmatrix};\ \text{pages 40 and 41} \qquad \textbf{(677)}$$

where the *greater* of the variances is given the index 1.

If the test quotient **(677)** is *smaller* than the significance limit, then **(678)**–**(693)** are valid; if the quotient attains or exceeds the significance limit, then **(694)**–**(701)** are valid.

If the test quotient **(677)** is *smaller* than the significance limit, then it is reasonable to assume that $(\sigma^2_{y\cdot x})_1 = (\sigma^2_{y\cdot x})_2$. The common variance $\bar{\sigma}^2_{y\cdot x}$ of the two regression lines can then be estimated under the condition of **(675)** as

$$\bar{s}^2_{y\cdot x} = \frac{(S_{y\cdot x})_1 + (S_{y\cdot x})_2}{n_1 + n_2 - 4};\ \nu = n_1 + n_2 - 4 \qquad \textbf{(678)}$$

(678) is used to test the hypothesis **(675a)**, i.e., $b_1 = b_2$. The test quotient for the difference between the two regression coefficients under the conditions of **(675)** is

$$\frac{b_1 - b_2}{s_{D_b}};\ \text{significance limit } t;\ 2P = 2\alpha;\ \nu_t = n_1 + n_2 - 4 \qquad \textbf{(679)}$$

$$\text{where } s^2_{D_b} = \textbf{(678)} \times \left(\frac{1}{S_{x_1}} + \frac{1}{S_{x_2}}\right) \qquad \textbf{(680)}$$

If the test quotient **(679)** is *smaller* than the significance limit, then **(681)**–**(693)** are valid. If the quotient *attains* or *exceeds* the significance limit, then the regression lines are not parallel, i.e., $b_1 \neq b_2$. In other words,

if the test quotient **(679)** is *smaller* than the significance limit, then the two regression lines may be regarded as **(681)**

The estimate of the common residual variance $\bar{\sigma}^2_{y\cdot x}$ when ditions of **(675a)** are fulfilled is

$$\bar{s}^2_{y\cdot x} \approx \textbf{(678)};\ \nu = n_1 + n_2 - 4$$

$$= \frac{(S_{y\cdot x})_1 + (S_{y\cdot x})_2 + \dfrac{(b_1 - b_2)^2}{1/S_{x_1} + 1/S_{x_2}}}{n_1 + n_2 - 3};\ \nu = n_1 + n_2 - 3$$

The estimate $\bar{b}_{yx}$ of the common regression coefficient $\boldsymbol{b}$; the conditions of **(675a)** are fulfilled is

$$\bar{b}_{yx} = \frac{(S_{xy})_1 + (S_{xy})_2}{S_{x_1} + S_{x_2}}$$

The estimate $s^2_{\bar{b}_{yx}}$ of the variance $\sigma^2_{\bar{b}_{yx}}$ of the common reg coefficient when the conditions of **(675a)** are fulfilled is

$$s^2_{\bar{b}_{yx}} \approx \frac{\textbf{(678)}}{S_{x_1} + S_{x_2}};\ \nu = n_1 + n_2 - 4 \qquad \text{(a)}$$

$$= \frac{\textbf{(682)}}{S_{x_1} + S_{x_2}};\ \nu = n_1 + n_2 - 3 \qquad \text{(b)}$$

The two lines may be considered as *identical* [hypothesis (6 when the test quotient

$$\frac{\hat{b} - \bar{b}}{s_{\hat{b}-\bar{b}}};\ \begin{Bmatrix} \nu = n_1 + n_2 - 4, \text{ when } s_{\hat{b}-\bar{b}} = \sqrt{\textbf{(687a)}} \\ \nu = n_1 + n_2 - 3, \text{ when } s_{\hat{b}-\bar{b}} = \sqrt{\textbf{(687b)}} \end{Bmatrix} \begin{matrix} \hat{b} = \textbf{(686)} \\ \bar{b} = \textbf{(683)} \end{matrix}$$

is *smaller* than the significance limit t ($2P = 2\alpha$, pages 32–3

$$\hat{b} = \frac{\bar{y}_1 - \bar{y}_2}{\bar{x}_1 - \bar{x}_2}$$

$$\left.\begin{aligned} s^2_{\hat{b}-\bar{b}} &\approx \textbf{(678)} \times K \\ &= \textbf{(682)} \times K \end{aligned}\right\} \text{ where } K = \textbf{(688)} \qquad \begin{matrix} \text{(a)} \\ \text{(b)} \end{matrix}$$

$$K = \frac{1}{(\bar{x}_1 - \bar{x}_2)^2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right) + \frac{1}{S_{x_1} + S_{x_2}}$$

The two parallel regression lines do not coincide [hypot **(675a d)**] when the test quotient **(685)** *attains* or *exceeds* the si cance limit. In this case the vertical and horizontal distances p_y p_x are often of interest.

The *vertical distance* p_y and its confidence limits, when the ditions of **(675 a d)** are fulfilled, are

$$p_y = |\bar{y}_1 - \bar{y}_2 - \bar{b}_{yx}(\bar{x}_1 - \bar{x}_2)|;\ \bar{b}_{yx} = \textbf{(683)}$$

Confidence limits for $p_{y\cdot x}$

$$\approx \textbf{(689)} \pm t_{2\alpha}\sqrt{\textbf{(684a)} \times [(1/n_1 + 1/n_2)(S_{x_1} + S_{x_2}) + (\bar{x}_1 - \bar{x}_2)^2]} \quad \text{(a)}$$

where $\nu_t = n_1 + n_2 - 4$

$$= \textbf{(689)} \pm t_{2\alpha}\sqrt{\textbf{(684b)} \times [(1/n_1 + 1/n_2)(S_{x_1} + S_{x_2}) + (\bar{x}_1 - \bar{x}_2)^2]} \quad \text{(b)}$$

where $\nu_t = n_1 + n_2 - 3$

The *horizontal distance* p_x and its confidence limits, when the c ditions of **(675a d)** are fulfilled, are

$$p_x = \left|\bar{x}_1 - \bar{x}_2 - \frac{\bar{y}_1 - \bar{y}_2}{\bar{b}_{yx}}\right|;\ \bar{b}_{yx} \text{ from } \textbf{(683)}$$

Confidence limits for p_x

$$\approx \text{ or } = \left|\bar{x}_1 - \bar{x}_2 - \frac{\bar{y}_1 - \bar{y}_2}{\bar{b}_{yx}(1 - k^2)}\right| \pm \frac{k}{\bar{b}_{yx}(1 - k^2)} \times \sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)\left(\bar{b}_{yx}\right)^2\left(1 - k^2\right)\left(S_{x_1} + S_{x_2}\right) + \left(\bar{y}_1 - \bar{y}_2\right)^2}$$

where $\bar{b}_{yx} = \textbf{(683)}$ and either $k = k_1 = \textbf{(693a)}$ or $k = k_2 = \textbf{(693}$ The approximation sign is for $k = k_1$, the equality sign for $k =$

$$\begin{matrix} k_1^2 \\ k_2^2 \end{matrix}\Bigg\} = \frac{t^2_{2\alpha}\, s^2_{\bar{b}_{yx}}}{(\bar{b}_{yx})^2};\ \begin{cases} s^2_{\bar{b}_{yx}} = 684\text{a};\ \nu_t = n_1 + n_2 - 4 & \text{(a)} \\ s^2_{\bar{b}_{yx}} = 684\text{b};\ \nu_t = n_1 + n_2 - 3 & \text{(b)} \end{cases}$$

When $k \leq 0.05$, the term $1 - k^2$ in **(692)** can be taken as 1.

If the test quotient **(677)** *attains* or *exceeds* the significance lim

ypothesis (676a), that $b_1 = b_2$, is then tested by means of the quotient (679), where

$$s^2_{D_b} = \frac{(s^2_{y\cdot x})_1}{S_{x_1}} + \frac{(s^2_{y\cdot x})_2}{S_{x_2}} \qquad \text{(a)}$$

egrees of freedom $\nu_t = (617\text{b})$ (694)

$$\text{with } k = \frac{(s^2_{y\cdot x})_1 S_{x_2}}{(s^2_{y\cdot x})_1 S_{x_2} + (s^2_{y\cdot x})_2 S_{x_1}} \qquad \text{(b)}$$

ignificance limit $t_{2\alpha}$, with ν_t from (617b) and k from (694b)

If the test quotient (679) fitted to (694) is *smaller* than the significance limit, then it can be assumed that $b_1 = b_2$. The common regression coefficient is then

$$\bar{b}_{yx} = \frac{\dfrac{(S_{xy})_1}{(s^2_{y\cdot x})_1} + \dfrac{(S_{xy})_2}{(s^2_{y\cdot x})_2}}{\dfrac{S_{x_1}}{(s^2_{y\cdot x})_1} + \dfrac{S_{x_2}}{(s^2_{y\cdot x})_2}} \qquad (695)$$

with the estimated variance

$$s^2_{\bar{b}_{yx}} = \frac{1}{\dfrac{S_{x_1}}{(s^2_{y\cdot x})_1} + \dfrac{S_{x_2}}{(s^2_{y\cdot x})_2}} \qquad (696)$$

Provided that the sample sizes n_1 and n_2 are *large*, the hypothesis (476a c) that the two parallel regression lines are *identical* can be tested approximately by means of the quotient (685), where

$$\bar{b} = (686)$$

$$s^2_{\bar{b}\text{-}\bar{b}} = \frac{1}{(\bar{x}_1 - \bar{x}_2)^2}\left[\frac{(s^2_{y\cdot x})_1}{n_1} + \frac{(s^2_{y\cdot x})_2}{n_2} + (696)\right] \qquad (697)$$

Significance limit $|\varepsilon_\alpha|$, page 28

the *vertical* distance is

$$p_y = (689), \text{ where } \bar{b}_{yx} = (695) \qquad (698)$$

with confidence limits

$$\approx (698) \pm |\varepsilon_\alpha| \times \sqrt{\frac{(s^2_{y\cdot x})_1}{n_1} + \frac{(s^2_{y\cdot x})_2}{n_2} + (\bar{x}_1 - \bar{x}_2)^2 \times (696)} \qquad (699)$$

the *horizontal* distance is

$$p_x = (691), \text{ where } \bar{b}_{yx} = (695) \qquad (700)$$

with confidence limits

$$\approx \bar{x}_1 - \bar{x}_2 - \frac{\bar{y}_1 - \bar{y}_2}{\bar{b}_{yx}(1-k^2)} \pm \frac{k}{\bar{b}_{yx}(1-k^2)} \times$$

$$\times \sqrt{\left[\frac{(s^2_{y\cdot x})_1}{n_1} + \frac{(s^2_{y\cdot x})_2}{n_2}\right]\frac{(\bar{b}_{yx})^2(1-k^2)}{(496)} + (\bar{y}_1 - \bar{y}_2)^2} \qquad (701)$$

$\left[k^2 = \dfrac{\varepsilon^2_\alpha \times (696)}{(\bar{b}_{yx})^2}\right.$, ε_α, page 28, $\varepsilon^2_\alpha = \chi^2$, $\nu = 1$, $1\int_\nu = 2\alpha$, page 36,
$\left.\bar{b}_{yx} = (695)\right]$

When $k \leq 0.05$, the term $1 - k^2$ in (701) can be taken as 1

Probit and logit regressions

With appropriate modifications, many of the formulae given in section 18 can be applied to probit and logit regressions For further details the reader is referred to the literature

Probit regression[11, 12, 24], tables on pages 54 and 55

Logit regression[25], tables on pages 56 and 57

19. The bivariate normal distribution: Regressions of the second kind

(Cf introduction to section 18, page 174)

Given are n pairs of observations x, y Both x and y are *random*, normally distributed variables

Regressions of the second kind are distinguished from those of the first kind by the existence of *two* regression lines

$$Y = \bar{y} + b_{yx}(x - \bar{x}) \qquad \text{(a)}$$
$$X = \bar{x} + b_{xy}(y - \bar{y}) \qquad \text{(b)} \qquad (702)$$

Estimates of the parameters of (702) and their variances are made by means of the appropriate formulae in section 18 In estimating the parameters of (702b), x and y in these formulae must be transposed

19A. The correlation coefficient

A further parameter of regressions of the second kind is the

When the correlation coefficient is less than, equal to, or greater than zero, the two regression coefficients b_{yx} and b_{xy} are likewise less than, equal to, or greater than zero (703)

The following relationships are valid for the correlation coefficient

$$\varrho = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \qquad \text{(a)}$$

and for its estimate (704)

$$r = \frac{s_{xy}}{s_x s_y} = \frac{S_{xy}}{\sqrt{S_x S_y}}, \ S_x \text{ and } S_y \text{ from (493)}, \ S_{xy} \text{ from (634)} \qquad \text{(b)}$$

The square of the correlation coefficient r^2 is also known as the coefficient (or index) of determination

From (704) it follows that

$$r = \sqrt{\frac{s_{xy}}{s_x^2} \times \frac{s_{xy}}{s_y^2}} = \sqrt{b_{yx} \times b_{xy}} \qquad (705)$$

From (115) it therefore follows that the correlation coefficient is also the *geometrical mean* of the two regression coefficients b_{yx} and b_{xy}

Under the hypothesis $\varrho = 0$ when $n \to \infty$, the correlation coefficient is asymptotically related to the Student distribution On the other hand,

$$\frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}} \qquad (706)$$

has a distribution of exact Student type with $\nu = n - 2$ degrees of freedom

The hypothesis can therefore be tested by means of the quotient

$$\frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}}, \text{ significance limit } \begin{cases} t_{2\alpha} & \text{for } n \leq 202 \quad \text{(a)} \\ |\varepsilon_\alpha| & \text{for } n > 202 \quad \text{(b)} \end{cases} \qquad (707)$$

where $\nu = n - 2$

(706) does not need to be calculated for $\nu \leq 200$ since the significance limits for r can be taken directly from the table on page 61 They are based on the following formula identical with (707a)

$$|r| = \frac{t_{2\alpha}}{\sqrt{\nu + t^2_{2\alpha}}}; \ \nu_t = n - 2 \qquad (708)$$

If the test statistics from **(706)** or **(708)** *attain* or *exceed* the corresponding significance limits, then the correlation coefficient and the two regression coefficients *differ* significantly from zero. If $r \neq 0$, then the distribution of the sample correlation coefficient r is complicated in form. However, its distribution can be approximately normalized by means of R. A. FISHER's z-transformation, as follows:

$$\left.\begin{aligned} z &= \tanh^{-1} r = \tfrac{1}{2}\ln\frac{1+r}{1-r} && \text{(a)}\\ \text{and}\quad r &= \tanh z = \frac{e^{2z}-1}{e^{2z}+1} && \text{(b)}\end{aligned}\right\}\quad \textbf{(709)}$$

Cf. also Hyperbolic functions, page 140. Tables for **(709a)** are to be found on page 62 and for **(709b)** on pages 64 and 65.

The variance of z (2 variables x, y) is

$$\sigma_z^2 = \frac{1}{n-3}\text{; cf. also page 62} \qquad \textbf{(710)}$$

The expectation ζ of z is

$$\left.\begin{aligned} \zeta &\approx \tanh^{-1}\varrho && \text{(a)}\\ &= \frac{\varrho}{2(n-1)} + \tanh^{-1}\varrho && \text{(b)}\end{aligned}\right\}\quad \textbf{(711)}$$

(711b) can as a rule be neglected (see below).

The following is derived from **(709)**–**(711)**:

Testing the difference between an estimate r and a hypothetical correlation coefficient ϱ

Test quotient

$$\frac{|z-\zeta|}{\sigma_z} = |z-\zeta|\sqrt{n-3};\ z \text{ and } \zeta \text{ from } \textbf{(709a)} \text{ and } \textbf{(711a)} \qquad \textbf{(712)}$$

Significance limit $|c_\alpha|$, page 28, or $c_{2\alpha}$, page 31, lower table.

If the test quotient **(712)** *is smaller than the significance limit, then* there is no evidence that the population correlation coefficient differs from ϱ.

Confidence limits for ϱ

$$\text{Prob}\left[\tanh\left(z-\frac{|c_\alpha|}{\sqrt{n-3}}\right) \leq \varrho \leq \tanh\left(z+\frac{|c_\alpha|}{\sqrt{n-3}}\right)\right] \approx 1-2\alpha \qquad \textbf{(713)}$$

Values for $\frac{|c_\alpha|}{\sqrt{n-3}}$ for $1-2\alpha = 0.95$ and 0.99 are given on page 63.

Comparison of two correlation coefficients ϱ_1 and ϱ_2

Testing the hypothesis $\varrho_1 = \varrho_2$ on the basis of the estimates r_1 and r_2 is effected by means of the following quotient:

$$\frac{|z_1 - z_2|}{\sqrt{\dfrac{1}{n_1-3}+\dfrac{1}{n_2-3}}}\text{; significance limit } |c_\alpha|\text{, page 28, or } c_{2\alpha}\text{, page 31} \qquad \textbf{(714)}$$

If the test quotient **(714)** is *smaller* than the significance limit, then it can be assumed that $\varrho_1 = \varrho_2$. The estimate of the common correlation coefficient is then

$$\bar{r} = \tanh\bar{z} = \tanh\frac{(n_1-3)z_1+(n_2-3)z_2}{n_1+n_2-6} \qquad \textbf{(715)}$$

$$\text{and } \sigma_{\bar{z}}^2 = \frac{1}{n_1+n_2-6} \qquad \textbf{(716)}$$

The confidence limits for the common correlation coefficient are

$$\left.\begin{aligned}&\text{Prob}\left[\tanh\left(\bar{z}-|c_\alpha|\sigma_{\bar{z}}\right) \leq \bar{\varrho} \leq \tanh\left(\bar{z}+|c_\alpha|\sigma_{\bar{z}}\right)\right]\\ &= 1-2\alpha\text{; where } \sigma_{\bar{z}} = \sqrt{(716)}\end{aligned}\right\}\quad \textbf{(717)}$$

Comparison of several correlation coefficients

Given are k estimates $r_1, r_2, \ldots, r_i, \ldots, r_k$ from k bivariate samples

$$\sum_1^k (n_i-3)(z_i-\zeta)^2\text{; significance limit } \chi^2\text{; } 1f_r = \nu_{\chi^2} = k\text{; pages 36–39}$$

z_i and ζ from **(709a)** and **(711a)**.

If the hypothetical value is unknown, then its es

$$\bar{z} = \frac{\sum_1^k (n_i-3)z_i}{\sum_1^k (n_i-3)}$$

with variance

$$\sigma_{\bar{z}}^2 = \frac{1}{\sum_1^k (n_i-3)}$$

Testing the hypothesis $\varrho_1 = \varrho_2 = \cdots = \varrho_k = \bar{\varrho}$ is by means of the test statistic

$$\sum_1^k (n_i-3)(z_i-\bar{z})^2\text{; significance limit } \chi^2\text{; } 1f_r = 2 \quad \nu_{\chi^2} = k-1\text{; pages 36–39}$$

If the test statistic **(721)** is *smaller* than the significar it can be assumed that $\varrho_1 = \varrho_2 = \cdots = \varrho_k = \bar{\varrho}$. The est common correlation coefficient $\bar{\varrho}$ is then approximat

$$\bar{r} \approx \tanh(\bar{z} - a\tanh\bar{z})$$

where $\bar{z}$ is from **(719)** and

$$a = \frac{\sum_1^k\left(\dfrac{n_i-3}{n_i-1}\right)}{2\sum_1^k (n_i-3)}$$

The *confidence limits* for the common correlation coe then approximately

$$\text{Prob}\left[\tanh\left(\bar{z}-a\tanh\bar{z}-|c_\alpha|\sigma_{\bar{z}}\right) \leq \bar{\varrho} \leq\right.$$
$$\left.\leq \tanh\left(\bar{z}-a\tanh\bar{z}+|c_\alpha|\sigma_{\bar{z}}\right)\right] \approx 1-2\alpha$$

$\bar{z}$ from **(719)**, a from **(723)**, $\sigma_{\bar{z}} = \sqrt{(720)}$, and significanc page 28.

Examples, section 19A

Example 45. Given are $r = 0.3223$, $n = 34$. Does r diffe ($2\alpha = 0.05$)? Since $\nu = 32$ and the corresponding limit (0.3388, the hypothesis $r = 0$ cannot be rejected.

Example 46. Given are $r = 0.613$, $n = 42$. Required a confidence limits for ϱ:

$$z = 0.71371 \text{ (page 62)}$$
$$c_\alpha\sigma_z = 0.31385 \text{ (page 63)}$$
$$z \pm c_\alpha\sigma_z = 0.400 \text{ to } 1.027$$

whence $\text{Prob}\,(\underbrace{0.380}_{\text{page 64}} \leq \varrho \leq \underbrace{0.773}_{\text{page 64}}) = 0.95$

Example 47

Given are		whence are obtained	
r_i	n_i	z_i	n_i-3
0.555	12	0.62558	9
0.590	20	0.67767	17
0.670	15	0.81074	12
0.621	9	0.72663	6
0.733	26	0.93518	23
0.800	13	1.09861	10
		page 62	

$\bar{z} = 63.73451/77 = 0.828$ [from **(719)**]; $\tanh\bar{z} = 0.67$

$\chi^2 = 1.815$; $\nu = 6 - 1 = 5$ [from **(721)**] page

The 0.05 significance limit for χ^2, $\nu = 5$, is 11.07 (page 36) it follows that the hypothesis $\varrho_1 = \varrho_2 = \cdots = \varrho_k = \bar{\varrho}$ cann jected.

$a = 5.0734/154 = 0.0329$ [from **(723)**]

S_x and S_y are from (493), S_{xy} from (634), r from (704). Calculation is facilitated by using the relationship

$$r^2 = \frac{S_{xy}}{S_x S_y} \times S_{xy}$$

Comparison of a bivariate sample having means $\bar{y}$ and $\bar{x}$ with an *independent* pair of observations x, y, that is to say, testing the hypothesis that (x, y) come from the same (normal) population $(\bar{x}, \bar{y})$, is made by means of the test statistic

$$\left.\begin{aligned} &\frac{n(n-2)}{2(n+1)(1-r^2)} \times \\ &\times \left[\frac{(x-\bar{x})^2}{S_x} + \frac{(y-\bar{y})^2}{S_y} - \frac{2S_{xy}(x-\bar{x})(y-\bar{y})}{S_x S_y}\right] \end{aligned}\right\} \quad (733)$$

Significance limits, degrees of freedom, etc. are all as in (732). (733) is a special case of (734) with $n_1 = 1$.

Simultaneous comparison of the means of *two* bivariate samples $(x, y)_1$ and $(x, y)_2$, that is to say, testing the hypothesis $(\mu_{y_1} = \mu_{y_2} \mid \mu_{x_1} = \mu_{x_2})$, is made by means of the following test statistic *when* $\sigma^2_{y_1} = \sigma^2_{y_2}$, $\sigma^2_{x_1} = \sigma^2_{x_2}$,

$$\left.\begin{aligned} &\frac{n_1 n_2 (n_1 + n_2 - 3)}{2(n_1 + n_2)(1 - r^2)} \times \left\{\frac{(\bar{x}_1 - \bar{x}_2)^2}{S_{x_1} + S_{x_2}} + \right. \\ &\left. + \frac{(\bar{y}_1 - \bar{y}_2)^2}{S_{y_1} + S_{y_2}} - \frac{2[(S_{xy})_1 + (S_{xy})_2](\bar{x}_1 - \bar{x}_2)(\bar{y}_1 - \bar{y}_2)}{(S_{x_1} + S_{x_2})(S_{y_1} + S_{y_2})}\right\} \end{aligned}\right\} \quad (734)$$

where

$$r^2 = \frac{[(S_{xy})_1 + (S_{xy})_2]^2}{(S_{x_1} + S_{x_2})(S_{y_1} + S_{y_2})}; \text{ for calculation cf. (732)} \quad (735)$$

Significance limit F; $P = \alpha$; $\nu_1 = 2$, $\nu_2 = n_1 + n_2 - 3$; pages 40 and 41. Otherwise as in (732).

Approximate tests, preliminary to (734), can be made as follows:

Testing the hypothesis $\sigma^2_{x_1} = \sigma^2_{x_2}$ and $\sigma^2_{y_1} = \sigma^2_{y_2}$ from (605)

Testing the hypothesis $r_1 = r_2$ from (714)

For further discussion of tests of the above hypotheses see PEARSON and WILKS[28].

19D. Confidence and tolerance limits

100 $(1-\alpha)$% confidence and tolerance limits are calculated by means of the formulae below on the basis of the estimates $\bar{x}$, $\bar{y}$, S_x, S_y, S_{xy} of a two-dimensional sample. b_{yx} and $s_{b_{yx}}$ are obtained from (632) and (637), b_{xy} and $s_{b_{xy}}$ likewise but with x and y transposed. Degrees of freedom of F: $\nu_1 = 2$, $\nu_2 = n - 2$; $1 - \alpha = 1 - P$; pages 40–41.

Confidence limits

$$\left.\begin{aligned} &\mu_y \mid \mu_x = \bar{y} + b_{yx}(\mu_x - \bar{x}) \pm s_{b_{yx}} \sqrt{2FS_x/n - (n-2)(\mu_x - \bar{x})^2} \quad \text{(a)} \\ &\mu_x \mid \mu_y = \bar{x} + b_{xy}(\mu_y - \bar{y}) \pm s_{b_{xy}} \sqrt{2FS_y/n - (n-2)(\mu_y - \bar{y})^2} \quad \text{(b)} \end{aligned}\right\} \quad (736)$$

(736a) and (736b) are identical *confidence ellipses*.

Tolerance limits

$$\left.\begin{aligned} &\left.\begin{aligned} &\boldsymbol{Y} \mid x = \bar{y} + b_{yx}(x - \bar{x}) \pm \\ &\qquad \pm s_{b_{yx}} \sqrt{2(n+1)FS_x/n - (n-2)(x-\bar{x})^2} \end{aligned}\right\} \text{(a)} \\ &\left.\begin{aligned} &\boldsymbol{X} \mid y = \bar{x} + b_{xy}(y - \bar{y}) \pm \\ &\qquad \pm s_{b_{xy}} \sqrt{2(n+1)FS_y/n - (n-2)(y-\bar{y})^2} \end{aligned}\right\} \text{(b)} \end{aligned}\right\} \quad (737)$$

(737a) and (737b) are identical *tolerance ellipses* (see below).

The *slopes* of the main axes X_0, Y_0 of the ellipses defined by (736) and (737) respectively, the so-called *orthogonal* regression coefficients, are

$$b_0, -\frac{1}{b_0} = \frac{S_y - S_x}{2S_{xy}} \pm \sqrt{1 + \left(\frac{S_y - S_x}{2S_{xy}}\right)^2} \quad (738)$$

where

$$k \begin{cases} = F/n(n-2) \text{ for confidence ellipse (736)} \\ = F(n+1)/n(n-2) \text{ for tolerance ellipse (737)} \end{cases}$$

Construction of ellipses

Rapid method: Calculation from (738) and (739) and tion from (315).

Exact method: From (736) or (737a) and/or (737b) in tion with (738) and (739), according to the accuracy requ

The equations of tangents to the confidence or toleran parallel to the coordinate axes are:

$$\left.\begin{aligned} &\text{Horizontal tangents: } y = \bar{y} \pm \sqrt{kS_y} \\ &\text{Abscissae of the points of contact: } x = \bar{x} \pm b_{xy}\sqrt{kS_y} \end{aligned}\right\} \text{(a}$$

$$\left.\begin{aligned} &\text{Vertical tangents: } x = \bar{x} \pm \sqrt{kS_x} \\ &\text{Ordinates of the points of contact: } y = \bar{y} \pm b_{yx}\sqrt{kS_x} \end{aligned}\right\} \text{(b}$$

where

$$k \begin{cases} = 2F/n(n-2) \text{ for confidence ellipse (736)} & \text{(a)} \\ = 2F(n+1)/n(n-2) \text{ for tolerance ellipse (737)} & \text{(b)} \end{cases}$$

The lengths of the sides of the rectangle formed by these which circumscribes the ellipse are:

Horizontal sides

$$l_h = 2\sqrt{kS_x} \quad \text{(a)}$$

Vertical sides

$$l_v = 2\sqrt{kS_y} \quad \text{(b)}$$

where k = (742)

Example 49. Given is the bivariate sample (Figs. 40 and

x	y	x	y	x	y	x
2.6	2.3	4.2	2.7	6.0	5.2	7.5
3.0	3.5	4.5	5.5	6.5	6.0	8.0
3.0	4.0	4.7	5.7	6.5	8.0	8.0
3.5	3.5	5.5	4.5	7.0	6.0	8.0
3.8	4.5	5.7	5.7	7.0	7.0	10.0

(a) The parameters are estimated.

(b) Using the formulae for the regression lines Y and X, orthogonal regression lines Y_0 and X_0, for the tolerance elli $\boldsymbol{Y} \mid x$ or $\boldsymbol{X} \mid y$, and for the horizontal and vertical tangents latter, the lengths of the sides of the rectangle formed by th gents and the lengths of the semi-axes of the ellipse are calc

(c) For purposes of comparison, the tolerance limits for and $\boldsymbol{X} \mid y$ are calculated using the appropriate formulae fo gression of the first kind.

(d) A comparison is made of the tolerance limits for $\boldsymbol{Y} \mid$ $\boldsymbol{X} \mid y$ of regressions of the second and first kind with $x =$. $y = \bar{y}$.

(e) $\bar{x}$ and $\bar{y}$ are compared.

(a) Estimates of parameters

$\bar{x} = 115.0/20 = 5.75$ $\quad$ $\bar{y} = 111.3/20 = 5.565$

$S_x = 740.92 - 5.75 \times 115 = 79.67$ $\quad$ $S_y = 679.39 - 5.565 \times 11 = 60.0055$

$s_x^2 = 79.67/19 = 4.193158$ $\quad$ $s_y^2 = 60.0055/19 = 3.1581$

$s_x = 2.04772$ $\quad$ $s_y = 1.77713$

$S_{xy} = 700.90 - 5.75 \times 111.3 = 60.925$ from (634)

$s_{xy} = 60.925/19 = 3.206579$

$r^2 = 60.925^2 (79.67 \times 60.0055) = 0.776435170) = (70$

$1 - r^2 = 0.223564830$

$r = 0.881155$

$b_{yx} = 60.925/79.67 = 0.7647170$ from (632)

$-\frac{1}{b_4} = (60.0055 - 79.67)/(2 \times 60.925)$

$\pm\sqrt{1 + (-0.161382848)^2} = 0.85156$ and

-1.17432 from (738)

= 60.0055 × 0.22356483 = 13.4151194 from (636c)

= 13.4151194/18 = 0.745284411 from (635a)

= 0.745284411/79.67 = 0.009354643 from (637a)

= 0.0967224

= 79.67 × 0.22356483 = 17.8114100 from (636c)*

= 17.8114100/18 = 0.989522777 from (635a)*

= 0.989522777/60.0055 = 0.01649053 from (637a)*

= 0.128416

) Formulae

ession lines

$= 5.565 + 0.7647(x - 5.75) = 1.1679 + 0.7647\,x$ from (702a)

$= 5.75 + 1.0153(y - 5.565) = 0.0997 + 1.0153\,y$ from (702b)

$y - \bar{y} + b_4(x - \bar{x}) = 0.6685 + 0.8516\,x$

$y - \bar{y} - \frac{1}{b_4}(x - \bar{x}) = 12.317 - 1.1743\,x$

rance ellipse $[F_{0.95}(2, 18) = 3.55$, page 40]

erance limits for $Y|x$

$= 5.565 + 0.7647(x - 5.75) \pm 0.09672 \times$
$\sqrt{593.94 - 18(x - 5.75)^2}$ from (737a)

lerance limits for $X|y$

$= 5.75 + 1.0153(y - 5.565) \pm 0.12842 \times$
$\sqrt{447.34 - 18(y - 5.565)^2}$ from (737b)

rizontal tangents y and abscissae of the points of contact

$= 5.565 \pm 4.99 = 0.58$ and 10.55
$= 5.75 \pm 5.06 = 0.69$ and 10.81 } from (741a) and (742b)

Vertical tangents x and ordinates of the points of contact

$= 5.75 \pm 5.74 = 0.01$ and 11.49
$= 5.565 \pm 4.39 = 1.18$ and 9.96 } from (741b) and (742b)

ngths of the sides of the resulting rectangle

Horizontal sides $l_h = 11.48$
Vertical sides $l_v = 9.98$ } from (743) and (742b)

ngths of the semi-axes of the ellipse

$= \sqrt{\frac{3.55 \times 21}{20 \times 18}} \times$

$\sqrt{79.67 + 60.0055 \pm \sqrt{139.6755^2 - 4(4780.6382 - 60.925^2)}}$
$= 7.38$ and 1.83 from (739) and (740b)

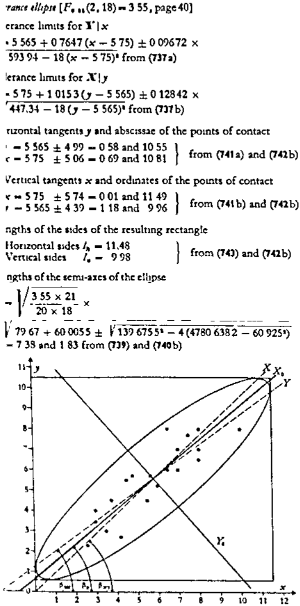


Fig 40 Tolerance ellipse, example 49

* With x and y transposed

(c) Tolerance limits for $Y|x$ and $X|y$ calculated from the formulae for a regression of the first kind ($t_{1\alpha=0.95, \nu=18} = 2.1009$, page 32)

$Y|x = 5.565 + 0.7647(x - 5.75) \pm 0.2032 \times$
$\sqrt{83.6535 + (x - 5.75)^2}$ from (669)

$X|y = 5.75 + 1.4070(y - 5.565) \pm 0.3739 \times$
$\sqrt{45.4659 + (y - 5.565)^2}$ from (674)

(d) Tolerance limits for $Y|x$ and $X|y$, with $x = \bar{x}$ and $y = \bar{y}$, calculated from the formulae for

	Regression of second kind	Regression of first kind
$Y\mid\bar{x}$	5.565 ± 2.3572 from (737a)	5.565 ± 1.8585 from (669)
$X\mid\bar{y}$	5.75 ± 2.7161 from (737b)	5.75 ± 2.5213 from (674)

(e) Comparison of $\bar{x}$ and $\bar{y}$ ($t_{2\alpha=0.95, \nu=18} \sim 2.09$)

$$\frac{5.75 - 5.565}{\sqrt{4.1932 + 3.1582 - 2 \times 3.2066}} = 0.191 \text{ from (731)}$$

The test statistic is smaller than the significance limit, so that the hypothesis $\bar{x} = \bar{y}$ cannot be rejected

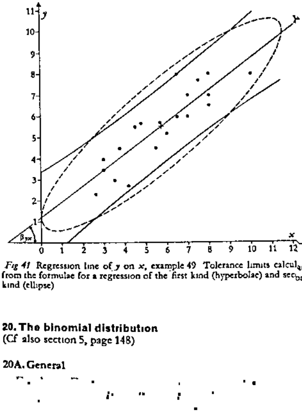


Fig 41 Regression line of y on x, example 49 Tolerance limits calculated from the formulae for a regression of the first kind (hyperbolae) and second kind (ellipse)

20. The binomial distribution

(Cf also section 5, page 148)

20A. General

$$\left.\begin{aligned} f(x) = P_x &= \binom{N}{x} p^x q^{N-x} \\ P_0 &= \binom{N}{0} p^0 q^N = q^N \\ P_1 &= \binom{N}{1} p^1 q^{N-1}, \ldots \\ P_N &= \binom{N}{N} p^N q^0 = p^N \end{aligned}\right\} \quad (744)$$

where $0 \leq p \leq 1$ and $q = 1 - p$

The individual probabilities P_x of (744) correspond to the terms of the binomial series developed from $(q + p)^N$ [cf. (113)] On the binomial coefficient $\binom{N}{x}$ cf (100)–(106), page 136

From (744) follow the recursion formulae

$$\dot{P}_{x+1} = \dot{P}_x \times \frac{p}{q} \times \frac{N-x}{x+1} \quad \text{(a)}$$
$$\dot{P}_{x-1} = \dot{P}_x \times \frac{q}{p} \times \frac{x}{N-x+1} \quad \text{(b)} \qquad (745)$$

Example 50. Calculate all the individual probabilities $\dot{P}_x$ for $p = 0.3$ and $N = 7$.

Calculations are made from (745a) starting from $x = 0$. $p/q = 3/7$.

$$\dot{P}_0 = \left(\frac{7}{10}\right)^7 \qquad = 0.0823543$$
$$\dot{P}_1 = \dot{P}_0 \times \frac{3}{7} \times \frac{7}{1} = \dot{P}_0 \times \frac{21}{7} = 0.2470629$$
$$\dot{P}_2 = \dot{P}_1 \times \frac{3}{7} \times \frac{6}{2} = \dot{P}_1 \times \frac{18}{14} = 0.3176523$$
$$\dot{P}_3 = \dot{P}_2 \times \frac{3}{7} \times \frac{5}{3} = \dot{P}_2 \times \frac{15}{21} = 0.2268945$$

A study of the series 21/7, 18/14, 15/21 at once reveals the :gular manner in which the numerators and denominators of the :cursion factors decrease and increase respectively. The further ctors for calculating $\dot{P}_4, \dot{P}_5, \ldots$ can therefore be assumed to be 2/28, 9/35, 6/42 and 3/49, giving

$\dot{P}_4 = 0.0972405$

$\dot{P}_5 = 0.0250047$

$\dot{P}_6 = 0.0035721$

$\dot{P}_7 = 0.0002187$

Check: $\sum_0^N \dot{P}_x = 1$

The individual probabilities for $N = 1, 2, \ldots, 99, 100$ and $= 0.01, 0.02, \ldots, 0.49, 0.50$ can be obtained in a different manner ing the tables on pages 70–77 (logarithms of binomial coeffi- :nts) and 78–84 (logarithms of powers of p and q).

Example 51. Calculate $\dot{P}_1$ for $p = 0.3$ and $N = 7$.

$\log \binom{7}{1} = 0.84510$ (page 70)

$\log p^1 = 0.47712 - 1$ (page 82)

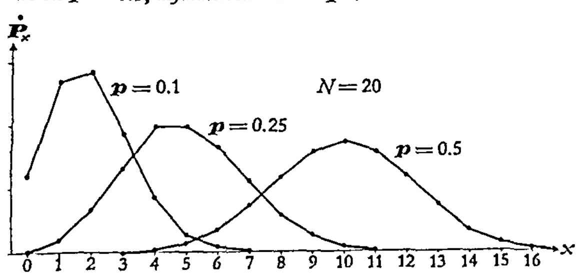
$\log q^6 = 0.07059 - 1$ (page 82)

$\log \dot{P}_1 = 1.39281 - 2 = 0.3928 - 1$

$\dot{P}_1 = 0.2471$ (page 11)

For binomial coefficients with $N > 100$ see under 'Binomial Co- icients', page 136. For calculating powers of p and q, logarithms th 7 or more places should be used*.

The binomial distribution is a *discrete* distribution. It is *symmetri-* when $p = 0.5$, *asymmetrical* when $p \neq 0.5$.



.42. Binomial distribution, $N = 20$, $p = 0.1$, 0.25 and 0.5.

3. Parameters of the binomial distribution

As shown by (744), the binomial distribution is fully character- d by the probability p and the number of trials N, so that it can represented by the expression 'binomial distribution (p; N)'. mean and variance are respectively

$$\mu_x = Np = \text{expectation of (749)} \qquad (746)$$

$$\sigma_x^2 = Npq = q\mu_x = \text{expectation of (750)} \times \frac{N}{N-1}$$

For any given sample size N (N trials) the variance of nomial distribution is greatest when $p = 0.5$, least when p $q = 0$.

The best estimate of p from a sample of size N in wh event E occurs x times is

$$p = x/N$$

The following are derived from (746)–(748):

Estimate of μ_x

$$\bar{x} = Np = x$$

Estimate of σ_x^2

$$s_x^2 = Npq = \frac{x(N-x)}{N}$$

The mean and variance of the *relative* frequency x/N are

$$\mu_{x/N} = p = \text{expectation of (748)}$$

$$\sigma_{x/N}^2 = \frac{pq}{N} = \text{expectation of (753)} \times \frac{N}{N-1}$$

The corresponding estimates are

for the mean = (748)

for the variance: $s_p^2 = \dfrac{pq}{N} = \dfrac{x(N-x)}{N^3} = \dfrac{1}{N^2} s_x^2$

Example 52. In 64 trials the event x occurs 6 times. Estima s_x^2 and s_p^2.

$p = 6/64 = 0.09375$ *from* (748)

$s_x^2 = 0.09375 \times 58 = 5.4375$ from (750)

$s_p^2 = 5.4375/64^2 = 0.001327515$ from (753)

20C. Cumulative probabilities of the binomial distributio

The calculation of cumulative probabilities in discrete distr tions has been dealt with fully in section 5 (page 149). Here s practical applications are indicated.

Let p be the probability of the event E, q that of the e non-E. $\dot{P}_x$ is defined in (744).

The probability that the event E

- will occur exactly $x = k$ times is given by (370) (a)
- will *not* occur exactly $x = k$ times is given by (371) (b)
- will occur *at the most* or *less* than $x = k$ times is given by (372) (c)
- will occur *at least* or *more* than $x = k$ times is given by (373) (d)
- will occur at least $x = k$ times *but at the most* $x = s$ times ($k < s$) is given by (374) (e)
- will occur *less* than $x = k$ times *or more* than $x = s$ times ($k < s$) is given by (375) (f)

(7

Examples of the calculation of probabilities of this kind are giv in section 5, page 150. The following is an additional example.

Example 53. Let p be the probability of the occurrence of event E in a population. What size N must a sample have if t probability that the event E occurs *at least once* is p^*?

From (754d) and (373) it follows that

$$\text{Prob}(x \geq 1) = \sum_1^N \dot{P}_x \qquad \text{(from 373b)}$$
$$= 1 - \dot{P}_0 \qquad \text{(from 373a)}$$

In accordance with (744), $\dot{P}_0 = q^N$, whence

$$p^* = 1 - q^N$$

that is, $N \sim \dfrac{\log(1-p^*)}{\log q} = \dfrac{\log(1-p^*)}{\log(1-p)}$ (75

Application. Let the probability of throwing a six with a d be 1/6. How many throws must be made in order to throw a si at least once with a probability $p^* \geq 0.99$?

* Tables of $f(x)$ and the cumulative distribution $\sum_x^N f(x)$ for $N = 2, 3, \ldots, 49$ $p = 0.01, 0.02, \ldots, 0.5$ are to be found in the literature [3,4].

From (755)

$$N = \frac{\log(1-0.99)}{\log(1-1/6)} = \frac{\log 0.01}{\log 5/6} \sim \frac{-2}{-0.0792} = 25.25$$

It follows that 26 throws must be made in order that, with a probability $\mathfrak{p}^* \geqq 0.99$, at least one six will be thrown (with 25 throws $\mathfrak{p}^*$ would be a little under 0.99).

20D. The binomial and the normal distribution

As shown by Figure 42, with $p = ½$, the binomial distribution closely resembles the normal distribution even with *fairly small* samples. This is not the case with more extreme values of p (cf. $p = 0.1$). As shown by Figure 43, however, with increasing sample size the binomial distribution approximates to the normal distribution even with more extreme values of p. In other words

With increasing sample size N the binomial distribution (p, N) tends toward the normal distribution $(Np, \sqrt{Npq})$. The closer p lies to 0.5, the greater is this tendency:

$$\binom{N}{x} p^x q^{N-x} \to \frac{1}{\sqrt{2\pi Npq}} e^{-(x-Np)^2/2Npq} \qquad (756)$$

as $N \to \infty$

With large sample sizes N, in accordance with the definitions

$$\text{Prob}(x \leq x_p) = \sum_0^{x_p} \dot{P}_x = \mathfrak{p}$$

$$\text{Prob}(\varepsilon \leq \varepsilon_p) = \int_{-\infty}^{\varepsilon_p} \text{ of the standardized normal distribution}$$

it follows from (756) that

$$\text{Prob}(x \leq x_p) \sim \text{Prob}(\varepsilon \leq \varepsilon_p) \qquad (757)$$

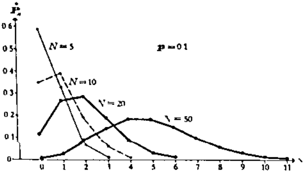


Fig. 43. Binomial distribution, $p = 0.1$, $N = 5, 10, 20, 50$

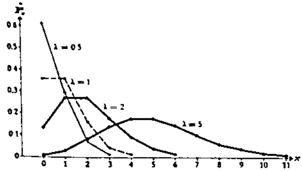


Fig. 44. Poisson distribution, $\lambda = 0.5, 1, 2, 5$

where

$$\varepsilon_p = \frac{x_p - Np}{\sqrt{Npq}}, \text{ (for } \varepsilon \text{ see page 28, right hand table)} \qquad (758)$$

or

$$x_p = Np + \varepsilon_p \sqrt{Npq}, \text{ (for } \varepsilon \text{ see page 28, left-hand table)} \qquad (759)$$

With smaller samples, the transformations (757) and (758) can be improved by using the so-called correction for continuity. In this case, $x + ½$ is used in place of x, whence

$$\varepsilon_p = \frac{x_p + ½ - Np}{\sqrt{Npq}}; \text{ (for } \varepsilon \text{ see page 28, right-hand table)} \qquad (760)$$

$$x_p = Np - ½ + \varepsilon_p \sqrt{Npq}; \text{ (for } \varepsilon \text{ see page 28, left-hand table)} \qquad (761)$$

From the definitions

$$\text{Prob}(x \geqq x_{p^*}) = 1 - \text{Prob}(x \leqq x_{p^*} - 1) = \mathfrak{p}^*$$

$$\text{Prob}(\varepsilon \leqq \varepsilon_{1-p^*}) = \int_{-\infty}^{\varepsilon_{1-p^*}} = 1 - \mathfrak{p}^*$$

it follows from (760) and (761) that

$$\varepsilon_{1-p^*} = \frac{x_{p^*} - ½ - Np}{\sqrt{Npq}}, \text{ (for } \varepsilon \text{ see page 28, right-hand table)} \qquad (762)$$

$$x_{p^*} = Np + ½ + \varepsilon_{1-p^*} \sqrt{Npq}, \text{ (for } \varepsilon \text{ see page 28, left-hand table)} \qquad (763)$$

Example 54. Given the binomial distribution ($p = 0.1$, $N = 40$), calculate the probabilities $\text{Prob}(x \leqq 3) = \mathfrak{p}$ and $\text{Prob}(x \geqq 6) = \mathfrak{p}^*$ using the approximate formulae (760)–(763)

$$\varepsilon_p = \frac{3.5 - 4}{\sqrt{3.6}} = -0.264 \text{ [from (760)]}$$

$\mathfrak{p} = 0.396$ (by linear interpolation in right-hand table, page 28)

$$\varepsilon_{1-p^*} = \frac{5.5 - 4}{\sqrt{3.6}} = 0.791 \text{ [from (761)]}$$

$1 - \mathfrak{p}^* = 0.786$

$\mathfrak{p}^* = 0.214$

The exact values of $\mathfrak{p}$ and $\mathfrak{p}^*$, rounded off to 3 decimal places, are 0.423 and 0.206

Example 55. For the binomial distribution of example 54, calculate x_p for $\mathfrak{p} = 0.1$ and x_{p^*} for $\mathfrak{p}^* = 0.05$ using the approximate formulae (760)–(763)

$$\left.\begin{aligned} \varepsilon_p &= -1.2816 \\ \varepsilon_{1-p^*} &= 1.6449 \end{aligned}\right\} \text{ page 28, left-hand table}$$

whence

$$x_p = 3.5 - 1.2816\sqrt{3.6} = 1.07 \text{ [from (761)]}$$

$$x_{p^*} = 4.5 + 1.6449\sqrt{3.6} = 7.62 \text{ [from (763)]}$$

Since x must be a whole number, this gives the results $x_p = 1$ and $x_{p^*} = 8$, which agree with the nearest exact values

A further and, if $p < q$, rather better approximation[29] is

$$\varepsilon_p = 2\left[\sqrt{(x_p + 1)\,q} - \sqrt{(N - x_p)\,p}\right] \qquad (764)$$

$$x_p = p\left(N + 1 - \frac{\varepsilon^2}{4}\right) + \frac{\varepsilon^2}{4} q - 1 + \varepsilon\sqrt{pq\left(N + 1 - \frac{\varepsilon^2}{4}\right)} \qquad (765)$$

where in (765) $\varepsilon = \varepsilon_p$

$$\varepsilon_{1-p^*} = 2\left[\sqrt{x_{p^*}\,q} - \sqrt{(N - x_{p^*} + 1)\,p}\right] \qquad (766)$$

$$x_{p^*} = p\left(N + 1 - \frac{\varepsilon^2}{4}\right) + \frac{\varepsilon^2}{4} q + \varepsilon\sqrt{pq\left(N + 1 - \frac{\varepsilon^2}{4}\right)} \qquad (767)$$

where in (767) $\varepsilon = \varepsilon_{1-p^*}$

The meaning of the symbols in (764)–(767) is the same as that in (760)–(763)

Example 56. Calculate examples 54 and 55 in accordance with (764)–(767)

$\varepsilon_p = 2\left(\sqrt{4 \times 0.9} - \sqrt{37 \times 0.1}\right) = -0.052$

$\mathfrak{p} = 0.479$

$\varepsilon_{1-p^*} = 2\left(\sqrt{6 \times 0.9} - \sqrt{35 \times 0.1}\right) = 0.906$

$\mathfrak{p}^* = 1 - 0.817 = 0.183$

$x_p = 0.979$

$x_{p^*} = 8.00$

20E. The binomial and the Poisson distribution

As shown by Figure 43, with small values of p the binomial distribution closely resembles the Poisson distribution. The following rule of thumb should be noted:

$$\left.\begin{array}{l} \binom{N}{x} p^x q^{N-x} \approx \dfrac{e^{-\lambda}\lambda^x}{x!}, \text{ where } \lambda = Np \\ \text{if} \\ \dfrac{Npq}{Np} \approx 1 \end{array}\right\} \quad (768)$$

20F. Confidence limits and significance limits

(a) *Confidence limits for* p, tables on pages 85–103 (or significance limits for $p = x/N$, cf. example 17, page 156)

In N trials, the event E occurs $x = k$ times. According to Clopper and Pearson[30], the confidence limits satisfying the equation

$$\text{Prob}(p_l < p < p_r \mid x = k, N) = 1 - 2\alpha;\ \alpha < 0.5$$

are the solutions of

$$\left.\begin{array}{ll} \sum\limits_{x=k}^{N} \binom{N}{x} p_l^x (1-p_l)^{N-x} = \alpha \text{ for } p_l & \text{(a)} \\ \text{and} & \\ \sum\limits_{x=0}^{k} \binom{N}{x} p_r^x (1-p_r)^{N-x} = \alpha \text{ for } p_r & \text{(b)} \end{array}\right\} \quad (769)$$

For $x = 0$ and $x = N$, only *one-sided* $1-\alpha$ limits are possible:

$$\left.\begin{array}{ll} \text{for } x = 0 & \\ 0 \text{ and } p_r = 1 - \text{antilog}\left(\dfrac{\log\alpha}{N}\right) & \text{(a)} \\ \text{for } x = N & \\ p_l = \text{antilog}\left(\dfrac{\log\alpha}{N}\right) \text{ and } N & \text{(b)} \end{array}\right\} \quad (770)$$

For $x = 0$ and $x = N$, the confidence limits for p given in the tables on pages 85–103 thus correspond not to $1 - 2\alpha$, but to $1-\alpha$ limits.

For $0 < x < N$ an exact solution of (769) is possible only by means of an iterative process. The tables on pages 85–98 were calculated in this way by computer.

Approximate solutions are

$$p_l, p_r = \frac{x \mp \frac{1}{2} + \dfrac{c^2}{2} \mp |c| \sqrt{(x \mp \frac{1}{2})\left(1 - \dfrac{x \mp \frac{1}{2}}{N}\right) + \dfrac{c^2}{4}}}{N + c^2} \quad (771)$$

where $c = c_\alpha$, page 28, left-hand table,

or, if $x \leqq N/2$

$$\left.\begin{array}{l} p_l, p_r = (A - B) \mp \sqrt{B[2 - (A-B) - A]} \\ \text{where} \\ A_{p_l}, A_{p_r} = \dfrac{x + \frac{1}{2} \mp \frac{1}{2} + \dfrac{c^2}{4}}{N+1} \\ B_{p_l}, B_{p_r} = \dfrac{c^2}{2}\left(\dfrac{x + \frac{1}{2} \mp \frac{1}{2}}{(N+1)^2}\right) \end{array}\right\} \quad (772)$$

where $c = c_\alpha$, page 28, left-hand table.

With larger samples, $\mp \frac{1}{2}$ in (771) and (772) can be ignored. (771) is the solution of (760) and (762) for p, (772) that of (764) and (766). The tables on pages 99–103 were calculated from (772) (for $x > 4$). In practice, (771) and (772) will seldom be required since ~~nge of the tables is sufficient for most cases.

B. Parameteıbows the confidence intervals for p for all possible

As shown by (744), the sizes $N = 30$ and $N = 10$.

ed by the probability p and the lim for limits not contained in the represented by the expression 'binomial' follows (the examples s mean and variance are respectively

$\mu_x = Np =$ expectation of (749)

cumulative distribution $\sum^{N} f(x)$ for $N = 2, 3, \ldots, 49$

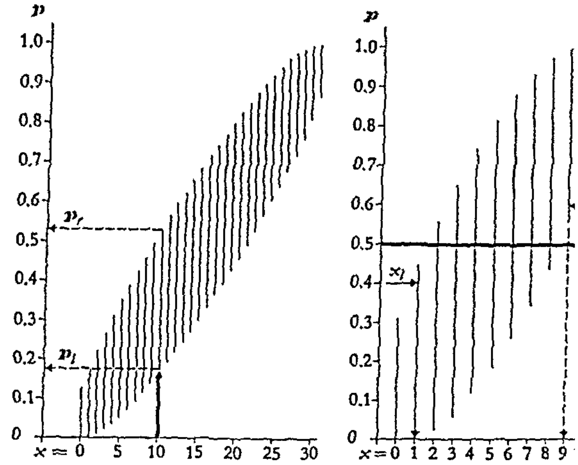


Fig. 45. Binomial distribution. Confidence limits for p; $N = 30$ and $N =$

(1) x or $100\,p_x$ ($= 100\,x/N$) lies *above* the tabulated values in N column.

$$\left.\begin{array}{l} N - x = x', \text{ or } 100 - 100\,p_x = 100\,p_x', \text{ is first calculated and} \\ \text{the corresponding limits } 100\,p_l' \text{ and } 100\,p_r' \text{ looked for in} \\ \text{the table. The required limits are:} \\ \quad \text{Lower } p_l = 100 - 100\,p_r' \\ \quad \text{Upper } p_r = 100 - 100\,p_l' \end{array}\right\} \quad (77$$

Example 57. $N = 150$, $x = 125$. $x' = 150 - 125 = 25$, or $100\,p_x' = 100 - 83.33 = 16.67$. For this the table gives $100\,p_l' = 11.10$ an $100\,p_r' = 23.64$, whence from (773) the required limits are 76.36 - 88.90.

(2) x or $100\,p_x$ ($= 100\,x/N$) lies between two values in an N column. $100\,p_x$ lies between $100\,p_x'$ and $100\,p_x''$ ($p_x' < p_x''$).

The limits $100\,p_l'$ and $100\,p_r'$ for $100\,p_x'$ and the limits $100\,p_l''$ and $100\,p_r''$ for $100\,p_x''$ are looked for in the table:

$100\,p_x''$	$100\,p_l''$	$100\,p_r''$
$100\,p_x'$	$100\,p_l'$	$100\,p_r'$
$(100\,p_x'' - 100\,p_x')$	$(100\,p_l'' - 100\,p_l') = B_l$	$(100\,p_r'' - 100\,p_r') = B_r$

If the quotient $\dfrac{100\,p_x - 100\,p_x'}{100\,p_x'' - 100\,p_x'} = A$

then the required limits are

$$100\,p_l = 100\,p_l' + (A \times B_l)$$
$$100\,p_r = 100\,p_r' + (A \times B_r) \quad (774)$$

Example 58. $N = 500$, $x = 427$, $100\,p_x = 85.40$

$100\,p_x'' = 86.00$	$100\,p_l'' = 82.64$	$100\,p_r'' = 88.92$
$100\,p_x' = 84.00$	$100\,p_l' = 80.48$	$100\,p_r' = 87.10$
Difference 2.00	2.16	1.82

$100\,p_x - 100\,p_x' = 85.40 - 84.00 = 1.40$
$A = 1.40/2.00 = 0.70$

$100\,p_l = 80.48 + (0.7 \times 2.16) = 81.99 = \underline{82.0}$
$100\,p_r = 87.10 + (0.7 \times 1.82) = 88.37 = \underline{88.4}$

(3) N lies between N_1 and N_2 ($N_1 < N_2$). For $100\,p_x$ ($= 100\,x/N$) interpolation is made in column N_1 to give the limits $100\,p_l^*$ and $100\,p_r^*$, in column N_2 to give the limits $100\,p_l^{**}$ and $100\,p_r^{**}$, in accordance with (774). The required limits are then

$$\left.\begin{array}{l} 100\,p_l = 100\,p_l^* + \dfrac{N - N_1}{N_2 - N_1}(100\,p_l^{**} - 100\,p_l^*) \\ 100\,p_r = 100\,p_r^* + \dfrac{N - N_1}{N_2 - N_1}(100\,p_r^{**} - 100\,p_r^*) \end{array}\right\} \quad (775)$$

Example 59. $N = 270$, $x = 22$, $100\,p_x = 8.15$. $N = 270$ lies between $N_1 = 250$ and $N_2 = 300$. The interpolated limits for $100\,p_x = 8.15$ in accordance with (774) are in column

$N_2 = 300$	$100\,p_l^{**} = 5.32$	$100\,p_r^{**} = 11.86$
$N_1 = 250$	$100\,p_l^* = 5.08$	$100\,p_r^* = 12.28$

$$\frac{N - N_1}{N_2 - N_1} = \frac{20}{50} = 0.4$$

$.00 p_l = 5.08 + (0.4 \times 0.24) = 5.18 = \underline{5.2}$

$.00 p_r = 12.28 - (0.4 \times 0.42) = 12.11 = \underline{12.1}$

4) N lies above 1000. For $100\,p_x$ ($= 100\,x/N$) the limits $100\,p_l'$ 1 $100\,p_r'$ are looked for in the column $N = 1000$. Then

$$\left.\begin{aligned} 100\,p_x - 100\,p_l' &= A \\ 100\,p_r' - 100\,p_x &= B \\ \text{d}\ 100\,p_l &= 100\,p_x - A\sqrt{1000/N} \\ 100\,p_r &= 100\,p_x + B\sqrt{1000/N} \end{aligned}\right\} \quad (776)$$

Example 60. Given are $N = 3000$ and $x = 69$, $100\,p_x = 2.30$. For $0\,p_x = 2.30$, column $N = 1000$ gives the limits $100\,p_l' = 1.46$ and $0\,p_r' = 3.44$

$A = 2.30 - 1.46 = 0.84$

$B = 3.44 - 2.30 = 1.14$

$\sqrt{1000/3000} = \sqrt{1/3} \sim 0.577$

$100\,p_l = 2.3 - (0.84 \times 0.577) = 1.82 = \underline{1.8}$

$100\,p_r = 2.3 + (1.14 \times 0.577) = 2.96 = \underline{3.0}$

(*b*) *Significance limits for* x, tables on pages 104–106 (or confidence mits for Np)

[illegible]

Example 61. Required are the 95% confidence limits for x for a ample of size $N = 10$ and a given $p = 0.5$

As shown by Figure 45, right, the *lower* limit x_l is fixed by that confidence interval for p whose *upper* limit p_r lies *closest* to the given p *without exceeding it* (a)

The *upper* limit x_r is fixed by that confidence interval for p whose *lower* limit p_l lies *closest* to the given p *without falling below it* (b)

(777)

In the table on page 85, $p_r = 44.50$ is in accordance with (777a) and $p_l = 55.50$ in accordance with (777b). The required limits for x are therefore $x_l = 1$ and $x_r = 9$

According to WILKS[31], the above significance limits correspond to the *distribution-free confidence limits for quantiles* $Q\,(p)$ (cf section 10F, page 161) when x_l is replaced by $x_l + 1$ and when p in the table is so chosen that it is of the same magnitude as p in $Q\,(p)$

In this connection it should be noted [cf (383)] that the postulated significance probability is reached when x *attains* or exceeds in an outward direction from Np the limits x_l or x_r

[illegible]

(one-tailed test) the sample originates from a population with $p > 0.05$ ($\alpha = 0.025$)

(two-tailed test) the sample originates from a population with $p \neq 0.05$ ($2\alpha = 0.05$)

On the basis of (760) and (762) or of (764) and (766) the following approximations are suitable for calculating the significance limits for x

$$x_l, x_r = Np \mp (\tfrac{1}{2} + t_\alpha \sqrt{Npq}) \quad (778)$$

(t_α, page 28, left hand table)

or, if $p < q$

$$\left.\begin{aligned} x_l + 1, x_r &= p\left(N + 1 - \frac{t^2}{4}\right) + \\ &+ \frac{t^2}{4}\,q \mp t\sqrt{pq\left(N + 1 - \frac{t^2}{4}\right)} \end{aligned}\right\} \quad (779)$$

($t = t_\alpha$, page 28, left-hand table)

(*c*) *Distribution-free tolerance limits for continuous distributions*, table on page 128 (cf. also sections 8C, page 155, and 10F, page 161)

The values of the sample sizes N in this table have been calculated by an iterative process based on a formula of WILKS[31], so that

$$\sum_{N-2k+1}^{N} \binom{N}{x} \beta_p^x (1 - \beta_p)^{N-x} \leq 1 - \beta_t \quad (780)$$

The rounded-off values are based on the approximations[32]

$$\left.\begin{aligned} N &\sim 1.03\,x + 4.74\,\chi^2 - 1 \quad \text{for } \beta_p = 0.90 \\ N &\sim 1.01\,x + 9.75\,\chi^2 - 1 \quad \text{for } \beta_p = 0.95 \\ N &\sim 1.00\,x + 49.75\,\chi^2 - 1 \quad \text{for } \beta_p = 0.99 \end{aligned}\right\} \quad (781)$$

where χ^2 is so chosen that $1\int_r$ of the table on pages 36–39 equals $1 - \beta_t$ for $\nu = 4\,x$

The approximation to N obtained from (781) is very close to (780).

20G. Binomial distribution: Miscellaneous

(*a*) *Arc-sine transformation*, table on page 69 (cf also 'Inverse trigonometric functions', page 139)

According to FREEMAN and TUKEY[29], the best transformation $x \rightarrow X$ for stabilizing the variance of the binomial distribution when $Np \geq 1$ is in most cases

$$\left.\begin{aligned} X &= \arcsin\sqrt{\frac{x}{N+1}} + \arcsin\sqrt{\frac{x+1}{N+1}} \\ &\text{with a variance within } \pm 6\% \text{ of} \\ s_X^2 &= \frac{1}{N + \frac{1}{2}}\begin{pmatrix}\text{angle in}\\ \text{radians}\end{pmatrix} \text{ or } \frac{821}{N + \frac{1}{2}}\begin{pmatrix}\text{angle in}\\ \text{degrees}\end{pmatrix} \end{aligned}\right\} \quad (782)$$

The mean $\bar{X}$ of the values thus transformed is approximately $2 \arcsin \sqrt{p}$

This transformation can be used in variance analysis and other operations

(*b*) With a given p, how large must the sample size N be for the event E to occur at least x times with a probability p^*? The solution of this problem for $x = 1$ is given in (755)

The simplest approximate solution for $x > 1$, on the basis of (766), is (when $p < q$)

$$N \sim \frac{1}{p}\left(\frac{t^2}{4} + x + t\sqrt{xq}\right) - 1 \quad (783)$$

where $t = t_{p^*}$

21. The Poisson distribution

21A. General

E is a random event occurring over a long period of observation† an infinite number of times but in a relatively short time† (in general the *observation unit t*) only rarely. The probability that in an observation unit t the event will occur 0, 1, 2, . . , x times is then

$$f(x) = P_x = \frac{e^{-\lambda}\lambda^x}{x!} = \underbrace{\frac{e^{-\lambda}\lambda^0}{0!}}_{= e^{-\lambda}},\ \frac{e^{-\lambda}\lambda^1}{1!},\ \frac{e^{-\lambda}\lambda^2}{2!} \quad \cdot \quad (784)$$

e = base of natural logarithms; t = observation unit, for λ see (787), page 188

[illegible]

Tables of $f(x)$ and the cumulative distribution $\sum_x P_x$ are given by MOLINA[2]

The simplest calculation of several successive individual probabilities is from the recursion formula

$$P_{x+1} = P_x \times \frac{\lambda}{x+1} \quad (785)$$

† Time has been chosen as an example. The same argument would apply, for instance, to surfaces and volumes

As shown by Figure 43, with small values of p the binomia distribution closely resembles the POISSON distribution. The fol lowing rule of thumb should be noted:

$$\left.\begin{array}{l} \binom{N}{x} p^x q^{N-x} \approx \dfrac{e^{-\lambda}\lambda^x}{x!}, \text{ where } \lambda = Np \\ \text{if} \\ \dfrac{Npq}{Np} \approx 1 \end{array}\right\} \quad (768$$

20 F. Confidence limits and significance limits

(a) *Confidence limits for p*, tables on pages 85–103 (or significanc imits for $p = x/N$, cf. example 17, page 156)

In N trials, the event E occurs $x = k$ times. According to CLOPPE and PEARSON [30], the confidence limits satisfying the equation

$$\text{Prob}\,(p_l < p < p_r \mid x = k, N) = 1 - 2\alpha;\ \alpha < 0.5$$

re the solutions of

$$\left.\begin{array}{ll} \sum\limits_{x=k}^{N} \binom{N}{x} p_l^x (1-p_l)^{N-x} = \alpha \text{ for } p_l & \text{(a)} \\ \text{nd} & \\ \sum\limits_{x=0}^{k} \binom{N}{x} p_r^x (1-p_r)^{N-x} = \alpha \text{ for } p_r & \text{(b)} \end{array}\right\} \quad (769$$

For $x = 0$ and $x = N$, only *one-sided* $1-\alpha$ limits are possible:

$$\left.\begin{array}{ll} \text{or } x = 0 & \\ 0 \text{ and } p_r = 1 - \text{antilog}\left(\dfrac{\log\alpha}{N}\right) & \text{(a)} \\ \text{or } x = N & \\ p_l = \text{antilog}\left(\dfrac{\log\alpha}{N}\right) \text{ and } N & \text{(b)} \end{array}\right\} \quad (770$$

For $x = 0$ and $x = N$, the confidence limits for p given in th ables on pages 85–103 thus correspond not to $1-2\alpha$, but to $1-$ mits.

For $0 < x < N$ an exact solution of (769) is possible only b ieans of an iterative process. The tables on pages 85–98 were ca ulated in this way by computer.

Approximate solutions are

$$p_l, p_r = \frac{x \mp \frac{1}{2} + \dfrac{c^2}{2} \mp |c| \sqrt{(x \mp \frac{1}{2})\left(1 - \dfrac{x \mp \frac{1}{2}}{N}\right) + \dfrac{c^2}{4}}}{N + c^2} \quad (77$$

here $c = c_\alpha$, page 28, left-hand table,

r, if $x \leq N/2$

$$\left.\begin{array}{l} p_l, p_r = (A - B) \mp \sqrt{B\,[2 - (A - B) - A]} \\ \text{here} \\ A_{p_l}, A_{p_r} = \dfrac{x + \frac{1}{2} \mp \frac{1}{2} + \dfrac{c^2}{4}}{N+1} \\ B_{p_l}, B_{p_r} = \dfrac{c^2}{2}\left(\dfrac{x + \frac{1}{2} \mp \frac{1}{2}}{(N+1)^2}\right) \end{array}\right\} \quad (77$$

here $c = c_\alpha$, page 28, left-hand table.

With larger samples, $\mp \frac{1}{2}$ in (771) and (772) can be ignore 71) is the solution of (760) and (762) for p, (772) that of (764) a 66). The tables on pages 99–103 were calculated from (772) (f = 4). In practice, (771) and (772) will seldom be required sin ...e of the tables is sufficient for most cases.

Parame... ...ws the confidence intervals for p for all possil shown by (744), t... sizes $N = 30$ and $N = 10$. oy the probability p and the ... presented by the expression 'bino... limits not contained in t iean and variance are respectively ... follows (the exampl

$= Np =$ expectation of (749)

... cumulative distribution $\sum^{N} f(x)$ for $N = 2, 3, \ldots, 49$

From (755)

$$N = \frac{\log(1 - 0.99)}{\log(1 - 1/6)} = \frac{\log 0.01}{\log 5/6} \sim \frac{-2}{-0.0792} = 25.25$$

It follows that 26 throws must be made in order that, with a probability $p^* \geq 0.99$, at least one six will be thrown (with 25 throws p^* would be a little under 0.99)

10D. The binomial and the normal distribution

As shown by Figure 42, with $p = 1/2$, the binomial distribution closely resembles the normal distribution even with *fairly small* samples. This is not the case with more extreme values of p (if $p = 0.1$). As shown by Figure 43, however, with increasing sample size the binomial distribution approximates to the normal distribution even with more extreme values of p. In other words:

With increasing sample size N the binomial distribution (p, N) tends toward the normal distribution $(Np, \sqrt{Npq})$. The closer p comes to 0.5, the greater is this tendency.

$$\binom{N}{x} p^x q^{N-x} \rightarrow \frac{1}{\sqrt{2\pi Npq}} e^{-(x-Np)^2/2Npq} \tag{756}$$

as $N \rightarrow \infty$

With large sample sizes N, in accordance with the definitions

$$\text{Prob}(x \leq x_p) = \sum_0^{x_p} \dot{P}_x = p$$

$$\text{Prob}(\epsilon \leq \epsilon_p) = \int_{-\infty}^{\epsilon_p} \text{of the standardized normal distribution}$$

it follows from (756) that

$$\text{Prob}(x \leq x_p) \sim \text{Prob}(\epsilon \leq \epsilon_p) \tag{757}$$

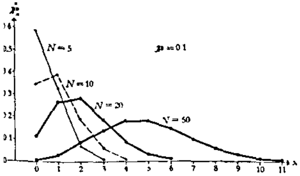


Fig. 43 Binomial distribution, $p = 0.1$, $N = 5, 10, 20, 50$

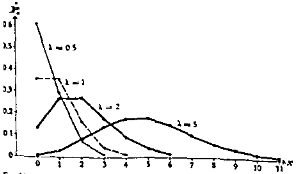


Fig. 44 Poisson distribution, $\lambda = 0.5, 1, 2, 5$

where

$$\epsilon_p = \frac{x_p - Np}{\sqrt{Npq}}, \text{ (for } \epsilon \text{ see page 28, right-hand table)} \tag{758}$$

or

$$x_p = Np + \epsilon_p \sqrt{Npq}, \text{ (for } \epsilon \text{ see page 28, left-hand table)} \tag{759}$$

With smaller samples, the transformations (757) and (758) can be improved by using the so-called correction for continuity. In this case, $x + 1/2$ is used in place of x, whence

$$\epsilon_p = \frac{x_p + 1/2 - Np}{\sqrt{Npq}}; \text{ (for } \epsilon \text{ see page 28, right-hand table)} \tag{760}$$

$$x_p = Np - 1/2 + \epsilon_p \sqrt{Npq}; \text{ (for } \epsilon \text{ see page 28, left-hand table)} \tag{761}$$

From the definitions

$$\text{Prob}(x \geq x_{p^*}) = 1 - \text{Prob}(x \leq x_{p^*} - 1) = p^*$$

$$\text{Prob}(\epsilon \leq \epsilon_{1-p^*}) = \int_{-\infty}^{\epsilon_{1-p^*}} = 1 - p^*$$

it follows from (760) and (761) that

$$\epsilon_{1-p^*} = \frac{x_{p^*} - 1/2 - Np}{\sqrt{Npq}}; \text{ (for } \epsilon \text{ see page 28, right-hand table)} \tag{762}$$

$$x_{p^*} = Np + 1/2 + \epsilon_{1-p^*} \sqrt{Npq}; \text{ (for } \epsilon \text{ see page 28, left hand table)} \tag{763}$$

Example 54 Given the binomial distribution ($p = 0.1$, $N = 40$), calculate the probabilities Prob $(x \leq 3) = p$ and Prob $(x \geq 6) = p^*$ using the approximate formulae (760)–(763).

$$\epsilon_p = \frac{3.5 - 4}{\sqrt{3.6}} = -0.264 \text{ [from (760)]}$$

$p = 0.396$ (by linear interpolation in right hand table, page 28)

$$\epsilon_{1-p^*} = \frac{5.5 - 4}{\sqrt{3.6}} = 0.791 \text{ [from (762)]}$$

$1 - p^* = 0.786$

$p^* = 0.214$

The exact values of p and p^*, rounded off to 3 decimal places, are 0.423 and 0.206

Example 55. For the binomial distribution of example 54, calculate x_p for $p = 0.1$ and x_{p^*} for $p^* = 0.05$ using the approximate formulae (760)–(763).

$$\left.\begin{aligned} \epsilon_p &= -1.2816 \\ \epsilon_{1-p^*} &= 1.6449 \end{aligned}\right\} \text{ page 28, left hand table}$$

whence

$$x_p = 3.5 - 1.2816\sqrt{3.6} = 1.07 \text{ [from (761)]}$$

$$x_{p^*} = 4.5 + 1.6449\sqrt{3.6} = 7.62 \text{ [from (763)]}$$

Since x must be a whole number, this gives the results $x_p = 1$ and $x_{p^*} = 8$, which agree with the nearest exact values

A further and, if $p < q$, rather better approximation is

$$\epsilon_p = 2\left[\sqrt{(x_p + 1)q} - \sqrt{(N - x_p)p}\right] \tag{764}$$

$$x_p = p\left(N + 1 - \frac{\epsilon^2}{4}\right) + \frac{\epsilon^2}{4}q - 1 + \epsilon\sqrt{pq\left(N + 1 - \frac{\epsilon^2}{4}\right)} \tag{765}$$

where in (765) $\epsilon = \epsilon_p$

$$\epsilon_{1-p^*} = 2\left[\sqrt{x_{p^*} q} - \sqrt{(N - x_{p^*} + 1)p}\right] \tag{766}$$

$$x_{p^*} = p\left(N + 1 - \frac{\epsilon^2}{4}\right) + \frac{\epsilon^2}{4}q + \epsilon\sqrt{pq\left(N + 1 - \frac{\epsilon^2}{4}\right)} \tag{767}$$

where in (767) $\epsilon = \epsilon_{1-p^*}$

The meaning of the symbols in (764)–(767) is the same as that in (760)–(763)

Example 56. Calculate examples 54 and 55 in accordance with (764)–(767)

$\epsilon_p = 2(\sqrt{4 \times 0.9} - \sqrt{37 \times 0.1}) = -0.052$

$p = 0.479$

$\epsilon_{1-p^*} = 2(\sqrt{6 \times 0.9} - \sqrt{35 \times 0.1}) = 0.906$

$p^* = 1 - 0.817 = 0.183$

$x_p = 0.979$

x

20E. The binomial and the Poisson distribution

As shown by Figure 43, with small values of p the binomial distribution closely resembles the POISSON distribution. The following rule of thumb should be noted:

$$\left.\begin{aligned}&\binom{N}{x} p^x q^{N-x} \approx \frac{e^{-\lambda}\lambda^x}{x!}, \text{ where } \lambda = Np\\ &\text{if}\\ &\frac{Npq}{Np} \approx 1\end{aligned}\right\} \quad (768)$$

20F. Confidence limits and significance limits

(a) *Confidence limits for p*, tables on pages 85–103 (or significance limits for $p = x/N$, cf. example 17, page 156)

In N trials, the event E occurs $x = k$ times. According to CLOPPER and PEARSON [30], the confidence limits satisfying the equation

$$\text{Prob}\,(p_l < p < p_r \mid x = k, N) = 1 - 2\alpha;\ \alpha < 0.5$$

are the solutions of

$$\left.\begin{aligned}&\sum_{x=k}^{N}\binom{N}{x} p_l^x (1-p_l)^{N-x} = \alpha \text{ for } p_l && \text{(a)}\\ &\text{and}\\ &\sum_{x=0}^{k}\binom{N}{x} p_r^x (1-p_r)^{N-x} = \alpha \text{ for } p_r && \text{(b)}\end{aligned}\right\} \quad (769)$$

For $x = 0$ and $x = N$, only *one-sided* $1 - \alpha$ limits are possible:

$$\left.\begin{aligned}&\text{for } x = 0\\ &0 \text{ and } p_r = 1 - \text{antilog}\left(\frac{\log\alpha}{N}\right) && \text{(a)}\\ &\text{for } x = N\\ &p_l = \text{antilog}\left(\frac{\log\alpha}{N}\right) \text{ and } N && \text{(b)}\end{aligned}\right\} \quad (770)$$

For $x = 0$ and $x = N$, the confidence limits for p given in the tables on pages 85–103 thus correspond not to $1 - 2\alpha$, but to $1 - \alpha$ limits.

For $0 < x < N$ an exact solution of (769) is possible only by means of an iterative process. The tables on pages 85–98 were calculated in this way by computer.

Approximate solutions are

$$p_l, p_r = \frac{x \mp \tfrac{1}{2} + \dfrac{c^2}{2} \mp |c| \sqrt{(x \mp \tfrac{1}{2})\left(1 - \dfrac{x \mp \tfrac{1}{2}}{N}\right) + \dfrac{c^2}{4}}}{N + c^2} \quad (771)$$

where $c = c_\alpha$, page 28, left-hand table,

or, if $x \leqq N/2$

$$\left.\begin{aligned}&p_l, p_r = (A - B) \mp \sqrt{B[2 - (A - B) - A]}\\ &\text{where}\\ &A_{p_l}, A_{p_r} = \frac{x + \tfrac{1}{2} \mp \tfrac{1}{2} + \dfrac{c^2}{4}}{N + 1}\\ &B_{p_l}, B_{p_r} = \frac{c^2}{2}\left(\frac{x + \tfrac{1}{2} \mp \tfrac{1}{2}}{(N+1)^2}\right)\end{aligned}\right\} \quad (772)$$

where $c = c_\alpha$, page 28, left-hand table.

With larger samples, $\mp \tfrac{1}{2}$ in (771) and (772) can be ignored. (771) is the solution of (760) and (762) for p, (772) that of (764) and (766). The tables on pages 99–103 were calculated from (772) (for $x > 4$). In practice, (771) and (772) will seldom be required since the range of the tables is sufficient for most cases.

Figure 45 shows the confidence intervals for p for all possible values of x for sample sizes $N = 30$ and $N = 10$.

Interpolation and extrapolation for limits not contained in the tables on pages 99–103 are carried out as follows (the examples are all for 95% limits):

Four different situations will be considered, of which (1) can be ... with (2), (3) or (4). In the latter case, calculation should

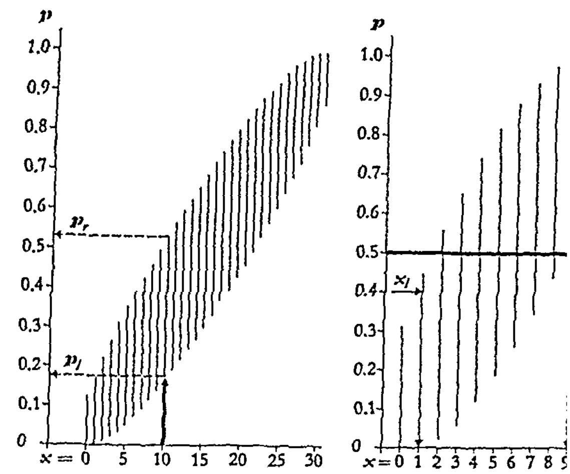


Fig. 45. Binomial distribution. Confidence limits for p; $N = 30$ and $N =$

(1) x or $100\,p_x$ ($= 100\,x/N$) lies *above* the tabulated values in N column.

$$\left.\begin{aligned}&N - x = x', \text{ or } 100 - 100\,p_x = 100\,p'_x, \text{ is first calculated and the corresponding limits } 100\,p'_l \text{ and } 100\,p'_r \text{ looked for in the table. The required limits are:}\\ &\text{Lower } p_l = 100 - 100\,p'_r\\ &\text{Upper } p_r = 100 - 100\,p'_l\end{aligned}\right\} \quad (7$$

Example 57. $N = 150$, $x = 125$. $x' = 150 - 125 = 25$, or $100\,p'_x$ $100 - 83.33 = 16.67$. For this the table gives $100\,p'_l = 11.10$ a $100\,p'_r = 23.64$, whence from (773) the required limits are 76.36 88.90.

(2) x or $100\,p_x$ ($= 100\,x/N$) lies between two values in an column. $100\,p_x$ lies between $100\,p'_x$ and $100\,p''_x$ ($p'_x < p''_x$).

The limits $100\,p'_l$ and $100\,p'_r$ for $100\,p'_x$ and the limits $100\,p''_l$ and $100\,p''_r$ for $100\,p''_x$ are looked for in the table:

$$\begin{array}{ccc} 100\,p''_x & 100\,p''_l & 100\,p''_r\\ 100\,p'_x & 100\,p'_l & 100\,p'_r\\ \hline (100\,p''_x - 100\,p'_x) & (100\,p''_l - 100\,p'_l) & (100\,p''_r - 100\,p'_r)\\ & = B_l & = B_r \end{array} \quad (774$$

If the quotient $\dfrac{100\,p_x - 100\,p'_x}{100\,p''_x - 100\,p'_x} = A$

then the required limits are

$$100\,p_l = 100\,p'_l + (A \times B_l)$$
$$100\,p_r = 100\,p'_r + (A \times B_r)$$

Example 58. $N = 500$, $x = 427$, $100\,p_x = 85.40$

$100\,p''_x = 86.00$	$100\,p''_l = 82.64$	$100\,p''_r = 88.92$
$100\,p'_x = 84.00$	$100\,p'_l = 80.48$	$100\,p'_r = 87.10$
Difference 2.00	2.16	1.82

$$100\,p_x - 100\,p'_x = 85.40 - 84.00 = 1.40$$
$$A = 1.40 / 2.00 = 0.70$$

$$100\,p_l = 80.48 + (0.7 \times 2.16) = 81.99 = \underline{82.0}$$
$$100\,p_r = 87.10 + (0.7 \times 1.82) = 88.37 = \underline{88.4}$$

(3) N lies between N_1 and N_2 ($N_1 < N_2$). For $100\,p_x$ ($= 100\,x/N$) interpolation is made in column N_1 to give the limits $100\,p_l^*$ and $100\,p_r^*$, in column N_2 to give the limits $100\,p_l^{**}$ and $100\,p_r^{**}$, in accordance with (774). The required limits are then

$$\left.\begin{aligned}&100\,p_l = 100\,p_l^* + \frac{N - N_1}{N_2 - N_1}(100\,p_l^{**} - 100\,p_l^*)\\ &100\,p_r = 100\,p_r^* + \frac{N - N_1}{N_2 - N_1}(100\,p_r^{**} - 100\,p_r^*)\end{aligned}\right\} \quad (775)$$

Example 59. $N = 270$, $x = 22$, $100\,p_x = 8.15$. $N = 270$ lies between $N_1 = 250$ and $N_2 = 300$. The interpolated limits for $100\,p_x = 8.15$ in accordance with (774) are in column

$N_2 = 300$	$100\,p_l^{**} = 5.32$	$100\,p_r^{**} = 11.86$

$$\frac{N - N_1}{N_2 - N_1} = \frac{20}{50} = 0.4$$

$$00\,p_l = 5.08 + (0.4 \times 0.24) = 5.18 = \underline{5.2}$$

$$00\,p_r = 12.23 - (0.4 \times 0.42) = 12.11 = \underline{12.1}$$

) N lies above 1000. For $100\,p_x$ ($=100\,x/N$) the limits $100\,p_l'$ $100\,p_r'$ are looked for in the column $N = 1000$. Then

$$\left.\begin{aligned} 100\,p_x - 100\,p_l' &= A \\ 100\,p_r' - 100\,p_x &= B \\ 100\,p_l &= 100\,p_x - A\sqrt{1000/N} \\ 100\,p_r &= 100\,p_x + B\sqrt{1000/N} \end{aligned}\right\} \quad (776)$$

Example 60. Given are $N = 3000$ and $x = 69$, $100\,p_x = 2.30$. For $p_x = 2.30$, column $N = 1000$ gives the limits $100\,p_l' = 1.46$ and $p_r' = 3.44$

$$A = 2.30 - 1.46 = 0.84$$

$$B = 3.44 - 2.30 = 1.14$$

$$\sqrt{1000/3000} = \sqrt{1/3} \sim 0.577$$

$$100\,p_l = 2.3 - (0.84 \times 0.577) = 1.82 = \underline{1.8}$$

$$100\,p_r = 2.3 + (1.14 \times 0.577) = 2.96 = \underline{3.0}$$

(*b*) *Significance limits for x*, tables on pages 104–106 (or confidence its for Np)

Example 61. Required are the 95% confidence limits for x for a mple of size $N = 10$ and a given $p = 0.5$

s shown by Figure 45, right, the *lower* limit x_l is fixed that confidence interval for p whose *upper* limit p_r is *closest* to the given p *without exceeding it* (a)

he *upper* limit x_r is fixed by that confidence interval r p whose *lower* limit p_l lies *closest* to the given p *ithout falling below it* (b) (777)

In the table on page 85, $p_r = 44.50$ is in accordance with (777a) nd $p_l = 55.50$ in accordance with (777b). The required limits for are therefore $x_l = 3$ and $x_r = 9$

According to Wilks[31], the above significance limits correspond o the *distribution free confidence limits for quantiles* $Q(p)$ (cf section 0F, page 161) when x_l is replaced by $x_l + 1$ and when p in the able is so chosen that it is of the same magnitude as p in $Q(p)$

In this connection it should be noted [cf (383)] that the postulated significance probability is reached when x *attains* or exceeds n an outward direction from Np the limits x_l or x_r

one-tailed test) the sample originates from a population with $p > 0.05$ ($\alpha = 0.025$)

two-tailed test) the sample originates from a population with $p \neq 0.05$ ($2\alpha = 0.05$)

On the basis of (760) and (762) or of (764) and (766) the following approximations are suitable for calculating the significance limits for x

$$x_l, x_r = Np \mp (\tfrac{1}{2} + c_\alpha \sqrt{Npq}) \quad (778)$$

c_α, page 29, left hand table)

or, if $p < q$

$$\left.\begin{aligned} x_l + 1, x_r &= p\left(N + 1 - \frac{c^2}{4}\right) + \\ &+ \frac{c^2}{4}\,q \mp c\sqrt{pq\left(N + 1 - \frac{c^2}{4}\right)} \end{aligned}\right\} \quad (779)$$

$c = c_\alpha$, page 29, left hand table)

(*c*) *Distribution free tolerance limits for continuous distributions*, table on page 128 (cf also sections 8C, page 155, and 10F, page 161)

The values of the sample sizes N in this table have been calculated by an iterative process based on a formula of Wilks[31], so that

$$\sum_{N-k+1}^{N} \binom{N}{x} \beta_p^x (1-\beta_p)^{N-x} \leq 1 - \beta_t \quad (780)$$

The rounded-off values are based on the approximations[32]

$$\left.\begin{aligned} N &\sim 1.03\,x + 4.74\,\chi^2 - 1 \quad \text{for } \beta_p = 0.90 \\ N &\sim 1.01\,x + 9.75\,\chi^2 - 1 \quad \text{for } \beta_p = 0.95 \\ N &\sim 1.00\,x + 49.75\,\chi^2 - 1 \quad \text{for } \beta_p = 0.99 \end{aligned}\right\} \quad (781)$$

where χ^2 is so chosen that $1\int_r$ of the table on pages 36–39 equals $1 - \beta_t$ for $\nu = 4x$.

The approximation to N obtained from (781) is very close to (780).

20G. Binomial distribution: Miscellaneous

(*a*) *Arc-sine transformation*, table on page 69 (cf. also 'Inverse trigonometric functions', page 139)

According to Freeman and Tukey[29], the best transformation $x \to X$ for stabilizing the variance of the binomial distribution when $Np \geq 1$ is in most cases

$$\left.\begin{aligned} &X = \arcsin\sqrt{\frac{x}{N+1}} + \arcsin\sqrt{\frac{x+1}{N+1}} \\ &\text{with a variance within } \pm 6\% \text{ of} \\ &s_X^2 = \frac{1}{N + \frac{1}{2}}\begin{pmatrix}\text{angle in}\\ \text{radians}\end{pmatrix} \text{ or } \frac{821}{N + \frac{1}{2}}\begin{pmatrix}\text{angle in}\\ \text{degrees}\end{pmatrix} \end{aligned}\right\} \quad (782)$$

The mean $\bar{X}$ of the values thus transformed is approximately $2\arcsin\sqrt{p}$

This transformation can be used in variance analysis and other operations

(*b*) With a given p, how large must the sample size N be for the event E to occur at least x times with a probability p^*? The solution of this problem for $x = 1$ is given in (755)

The simplest approximate solution for $x > 1$, on the basis of (766), is (when $p < q$)

$$N \sim \frac{1}{p}\left(\frac{c^2}{4} + x + c\sqrt{xq}\right) - 1 \quad (783)$$

where $c = c_{p^*}$

21. The Poisson distribution

21A. General

E is a random event occurring over a long period of observation† an infinite number of times but in a relatively short time† (in general the *observation unit t*) only rarely. The probability that in an observation unit t the event will occur 0, 1, 2, …, x times is then

$$f(x) = P_x = \frac{e^{-\lambda}\lambda^x}{x!} = \underbrace{\frac{e^{-\lambda}\lambda^0}{0!}}_{=e^{-\lambda}},\ \frac{e^{-\lambda}\lambda^1}{1!},\ \frac{e^{-\lambda}\lambda^2}{2!} \cdots \quad (784)$$

e = base of natural logarithms, t = observation unit; for λ see (787), page 188

The simplest calculation of several successive individual probabilities is from the recursion formula

$$P_{x+1} = P_x \times \frac{\lambda}{x+1} \quad (785)$$

† Time has been chosen as an example. The same argument would apply, for instance, to surfaces and volumes

Example 63. For the POISSON distribution ($\lambda = 1$) calculate the individual probabilities for x from 0 to 5.

$P_0 = 1/e = 0.367879$ $\quad P_3 = P_2 \times 1/3 = 0.061313$

$P_1 = P_0 \times 1 = 0.367879$ $\quad P_4 = P_3 \times 1/4 = 0.015328$

$P_2 = P_1 \times 1/2 = 0.183940$ $\quad P_5 = P_4 \times 1/5 = 0.003066$

Calculation of the *cumulative probabilities* is carried out according to the procedure given in section 5, page 148, with N replaced by infinity. It should also be noted that in the POISSON distribution the probability Prob ($x \gtrless k$) can be calculated only from the probability Prob ($x \lesseqgtr k - 1$), i.e.,

$$\text{Prob}(x \gtrless k) = 1 - \text{Prob}(x \lesseqgtr k - 1)$$

Example 64. How large must λ be for the event E to occur at least once during the observation unit t with a probability p^*? (This is an unusual problem in the POISSON distribution but sometimes occurs when the latter is used as an approximation to other distributions.)

The solution is obtained by using equation (129) on page 137. Here the numerical values for various probabilities p^* can also be found. For $p^* = 0.999$, λ *for example is 6.9.*

B. The addition theorem for the Poisson distribution

$x_{t_1}, x_{t_2}, \ldots, x_{t_k}$ are stochastically independent† random variables with POISSON distributions $(\lambda_{t_1}), (\lambda_{t_2}), \ldots, (\lambda_{t_k})$ respectively, then their sum $x = x_{t_1} + x_{t_2} + \cdots + x_{t_k}$ is likewise a POISSON distribution (λ) with $\lambda = \lambda_{t_1} + \lambda_{t_2} + \cdots + \lambda_{t_k}$. (786)

C. Parameters and their estimates

The mean of the POISSON distribution is

$\mu_{x_t} = \lambda_t =$ expectation of x_t (a)

and the variance

$\sigma^2_{x_t} = \lambda_t =$ expectation of x_t (b)

here t = observation unit to which x and λ_t relate. (787)

If a POISSON distribution with observation unit t is used to calculate another POISSON distribution with observation unit kt, then the mean and variance of the latter are

$$\mu_{x_{kt}}, \sigma^2_{x_{kt}} = k\lambda_t; (k > 0) \tag{788}$$

The equal magnitude of mean and variance in the POISSON distribution results in the following rule of thumb:

The ratio of mean to variance in a *discrete* distribution is approximately unity (say between $^{10}/_9$ and $^9/_{10}$), then a POISSON distribution is likely to approximate to it provided that the variable x can assume high (theoretically, infinitely high) values. (789)

Unbiased estimates of λ_t based on n *equal* observation units t are

$$\bar{x}_t = \frac{\Sigma x_t}{n} = \frac{\Sigma x_t f_t}{n} \quad \text{(a)}$$

$$s^2_t = \frac{\Sigma x_t^2 - (\Sigma x_t)^2/n}{n-1} = \frac{\Sigma x_t^2 f_t - (\Sigma x_t f_t)^2/n}{n-1} = \frac{S_t}{n-1} \quad \text{(b)} \tag{790}$$

$\bar{x}_t$ is the *better* (more efficient) estimate. Since it is also more quickly calculated it is the one usually used. With higher values of n ($n > 5$), however, the additional calculation of $(n-1)s^2$ [the numerator in (790b)] offers the advantage of being able to test whether the ratio $s^2/\bar{x}$ differs significantly from 1. The test quotient is

$$\frac{(n-1)s_t^2}{\bar{x}_t} = \frac{S_t}{\bar{x}_t} \tag{791}$$

Significance limit χ^2 with $\nu = n - 1$, $2\alpha = 1 \int_r$, pages 36–39

If the test quotient (791) attains or exceeds the significance limit, then the sample probably does not originate from a POISSON distribution. This leads to the following rule of thumb:

When (791) is significant, the sample could originate from a binomial distribution when $s^2 < \bar{x}$, from a binomial distribution with negative index when $s^2 > \bar{x}$. Cf. also BLISS[33]. (792)

† ... t_k must not overlap.

Example 65. In 60 minutes 12 events are observed. λ ... $12/1 = 12$. *In accordance with* (788), *the estimate of* $\lambda_{1\,\text{min}}$ ... $12/60 \sim 1/5$.

Example 66. In 60 minutes 12 events are observed, in 30 ... 8. In accordance with (786), $\lambda_{90\,\text{min}} \sim 12 + 8 = 20$, $\lambda_{1\,\text{min}} \sim$ ...

Example 67. In 100 observation periods of 1 minute e... event E is observed x_t times in f_t observation periods, as f...

x_t	f_t	$x_t f_t$	$x_t^2 f_t$	
0	5	0	0	
1	30	30	30	$\bar{x}_t = 2.36$ from (79...
2	24	48	96	
3	20	60	180	$S_t = 778 - 556.96$
4	12	48	192	$= 221.04$ from (...
5	4	20	100	
6	5	30	180	$\chi^2 = 93.661$,
7	0			$\nu = 99$ from (791)
8	0			
	$n = 100$	$\Sigma x = 236$ $= \lambda_{100\,\text{min}}$	$\Sigma x^2 = 778$	

In this case χ^2 lies far inside the significance limit of 0.05 (... $\alpha < 0.35$), so that the distribution *could* be a POISSON distrib... A *more efficient* test is provided by calculation of the *fitted* P... distribution in accordance with (784) with $\lambda = 2.36$, multipli... of the value obtained by n and then testing with χ^2 in accor... with (566) with degrees of freedom $\nu = k - 2$ from (569a), ... k = number of classes i.

21D. Transformations

As shown by Figure 44 (page 185), with increasing λ the sha... the POISSON distribution gradually (and fairly rapidly) appro... that of the normal distribution.

$$\frac{e^{-\lambda}\lambda^x}{x!} \to \frac{1}{\sqrt{2\pi\lambda}} e^{-\frac{(x-\lambda)^2}{2\lambda}}$$

as $\lambda \to \infty$.

The corresponding transformations are analogous to the t... formations of the binomial distribution to the normal distrib... using (760)–(763), with Np replaced by λ.

The following approximations are better[29]:

$$\left.\begin{aligned} c_p &= 2\left(\sqrt{x_p + 1} - \sqrt{\lambda}\right) \\ x_p &= \lambda + c_p\sqrt{\lambda} + \frac{c^2}{4} - 1 \\ c_{1-p^*} &= 2\left(\sqrt{x_{p^*}} - \sqrt{\lambda}\right) \\ x_{p^*} &= \lambda + c_{1-p^*}\sqrt{\lambda} + \frac{c^2}{4} \end{aligned}\right\} \lambda \geqq 1$$

Example 68. Calculate x_p and x_{p^*} for $p = p^* = 0.025$ of POISSON distribution ($\lambda = 99$).

$$x_p = 99 - 1.96\sqrt{99} + \frac{1.96^2}{4} - 1 = 79.46 \text{ from (795)}$$

$$x_{p^*} = 99 + 1.96\sqrt{99} + \frac{1.96^2}{4} = 119.46 \text{ from (797)}$$

Since x can have only discrete values, these results are roun... off to give 79 and 119. The exact values are 79 and 120. In this c... nection it should be noted that in such cases it is better to be on... safe side and round off outwards:

In order more adequately to meet the requirements Prob ($x \leqq x_p$) $\leqq p$ and Prob ($x \geqq x_{p^*}$) $\leqq p^*$, x_p should always be rounded off downwards, x_{p^*} always upwards. This also applies to approximations to other discrete distributions. (...

If rule (798) had been adhered to in example 68, the correct re... would have been obtained. However, this is not necessarily alw... the case when (798) is adhered to.

The following transformation[28] is suitable for stabilizing the variance

$$\left.\begin{aligned} &X = \sqrt{x} + \sqrt{x+1} \\ &\text{with variance } \sigma_X^2 \sim 1 \\ &\text{and mean } \quad \bar{X} \sim \sqrt{4\lambda + 1} \end{aligned}\right\} \quad (799)$$

The relationship between the Poisson and χ^2 distributions is given in (561) and (562), whence the following procedure for determining the *exact* values of x_p and x_{p^*}:

$$\left.\begin{aligned} &\text{(a) } x_p \text{ is required. The value } \chi^2 \leqq 2\lambda \text{ is looked for in the column } 1\int_2 = 1 - p \text{ of the } \chi^2 \text{ table on pages 36–39. From the degrees of freedom } \nu \text{ of this } \chi^2 \text{ it follows that} \\ &x_p = \frac{\nu}{2} - 1 \text{ when } \nu \text{ is even} \\ &\quad = \frac{\nu}{2} - 1.5 \text{ when } \nu \text{ is odd} \end{aligned}\right\} \quad (800)$$

$$\left.\begin{aligned} &\text{(b) } x_{p^*} \text{ is required. The value } \chi^2 \geqq 2\lambda \text{ is looked for in the column } 1\int_1 = p^* \text{ of the } \chi^2 \text{ table on pages 36–39. From the degrees of freedom } \nu \text{ of this } \chi^2 \text{ it follows that} \\ &x_{p^*} = \frac{\nu}{2} \text{ when } \nu \text{ is even} \\ &\quad = \frac{\nu}{2} + 0.5 \text{ when } \nu \text{ is odd} \end{aligned}\right\} \quad (801)$$

Example 69 Required are the $(1-2\alpha)$ limits for x when $\lambda = 32$ and $\alpha = 0.0005$. The left limit is obtained from (800) and is $\chi^2_{.9995} = 63.582 \leqq 64$ with $\nu = 31$, $x_l = 31/2 - 1.5 = 14$. The right limit is obtained from (801) and is $\chi^2_{.0005} = 64.526 \geqq 64$ with $\nu = 106$, $x_r = 106/2 = 53$

21F. Confidence limits and significance limits

(*a*) *Confidence limits for* λ (tables on pages 107 and 108)

In analogy with the binomial distribution, confidence limits for λ are solutions of the equations

$$\sum_{k=x}^{k=\infty} \frac{e^{-\lambda_l}\lambda_l^k}{k!} = \alpha \quad \text{and} \quad \sum_{k=0}^{k=x} \frac{e^{-\lambda_r}\lambda_r^k}{k!} = \alpha,\ \alpha < 0.5 \qquad \text{(a)} \quad \text{(b)} \quad (802)$$

for λ_l and λ_r

For $x = 0$ there is only one $(1-\alpha)$ confidence interval with the solution $\lambda_r = \chi$ [equation (129), page 137] The left limit λ_l is zero

For $x > 0$ only iterative solutions are possible The tables on pages 107 and 108 were calculated in this way by computer for values of λ up to 100 For values of $x > 100$ the formulae (804) were used (from FREEMAN and TUKEY's approximation[29])

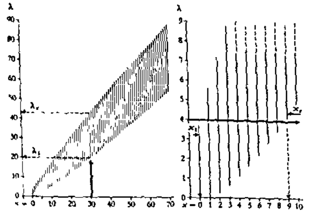


Fig 46 Poisson distribution, confidence limits for λ

For significance probabilities other than those in the tables on pages 107 and 108, *exact* limits for x up to 100 (or 99) can be calculated from the χ^2 table on pages 36–39 as follows:

Given x and α, then

$$\left.\begin{aligned} &\tfrac{1}{2}[\chi^2_{\alpha,\ \nu=2x}] = \lambda_l && \text{(a)} \\ &\tfrac{1}{2}[\chi^2_{1-\alpha,\ \nu=2(x+1)}] = \lambda_r && \text{(b)} \end{aligned}\right\} \quad (803)$$

where χ^2_α and $\chi^2_{1-\alpha}$ denote the α and $1-\alpha$ quantiles, α are to be found under $1\int_1$

Example 70. Required are the $(1-2\alpha)$ limits for λ wh and $\alpha = 0.05$. For λ_l the table is entered at $\nu = 2 \times 98 =$ $1\int_1 = 0.05$, giving $\chi_l^2 = 164.10$, $\lambda_l = 164.10/2 = 82.05$ F table is entered at $\nu = 2(98+1) = 198$ and $1\int_1 = 0.9$ $\chi_r^2 = 231.829$ $\lambda_r = 231.829/2 = 115.915$

For higher values of x, very good approximations are from (794) and (796):

$$\lambda_l, \lambda_r = \left(\frac{|z_\alpha|}{2} \mp \sqrt{x + ½ \mp ½}\right)^2$$

Example 71. Required are the $(1-2\alpha)$ confidence lir when $x = 99$ and $\alpha = 0.025$.

$$\lambda_l = \left(\frac{1.96}{2} - \sqrt{99 + ½ - ½}\right)^2 = 80.459$$

$$\lambda_r = \left(\frac{1.96}{2} + \sqrt{99 + ½ + ½}\right)^2 = 120.56$$

The exact values are 80.458 and 120.53

Example 72 In 12 minutes 24 events are observed Cal 95% limits for $\lambda_{12\,\min}$, $\lambda_{1\,\min}$, $\lambda_{1\,h}$. For $x = 24$ in the table o the limits 15.378 and 35.711 are given In accordance these give the following further limits

for $\lambda_{1\,\min} = 15.378/12$ and $35.711/12 = 1.2815$ and 2
for $\lambda_{1\,h} \quad = 15.378 \times 5$ and $35.711 \times 5 = 76.890$ and

The estimate of the limits for $\lambda_{x,t}$ must always be ma basis of the number of events x observed during the ol unit t, and *not* on the basis of this number *multiplied* following calculation in the case of example 72 would b

$x_{1\,\min} = 24/12 = 2$, limits $0.2422 - 7.2247$
or $x_{1\,h} \quad = 24 \times 5 = 120$, limits $99.49 - 143.52$

(*b*) *Significance limits for* x *when* λ *is given* (table on page

These limits meet the condition (390) with N replac They can be obtained without calculation from the limits for λ, as shown in Figure 46, right The procedure analogous to that for determining the corresponding lim binomial distribution For $\alpha \neq 0.025$ or 0.005, the left l tained from (800), the right limit from (801) Cf example page. For $n > 100$ (or 99), approximations are obtained and (797)

22. The hypergeometric distribution

22A General

Given are N balls, of which X are white and $N-X$ probability of drawing exactly x_1 white balls in N_1 dra

$$f(x_1 \mid X, N, N_1) = \frac{\binom{X}{x_1}\binom{N-X}{N_1-x_1}}{\binom{N}{N_1}} \qquad ($$

$$= \frac{N_1!\,(N-N_1)!\,X!\,(N-X)!}{N!\,x_1!\,(N_1-x_1)!\,(X-x_1)!\,(N-X-N_1+x_1)!} \qquad ($$

$f(x_1 \mid X, N, N_1)$ is known as the hypergeometric distrib (X, N, N_1 constant)

The corresponding fourfold table (cf section 22D, p

White	x_1	$N_1 - x_1$	N_1	$\equiv$	$x_1 \quad N_1 - x_1$ | N
Red	$X - x_1$	$N - X - N_1 + x_1$	$N - N_1$		$x_2 \quad N_2 - x_2$ | N
	X	$N - X$	N		$X \quad N - X$ | N

For $N \leqq 100$ the calculation of (805) is best made f means of the tables on pages 70–77 (cf explanation on p $N > 100$ from (b) by means of the tables on pages 26 a calculation can also be made with the aid of the recursio

$$f(x_1 + 1 \mid X) = [f(x_1 \mid X)] \times \frac{(N_1 - x_1)(X - x_1)}{(x_1 + 1)(N - X - N_1 + x}$$

and

$$f(x_1 \mid X + 1) = [f(x_1 \mid X)] \times \frac{(N - X - N_1 + x_1)(X +}{(N - X)(X + 1 - x_1)}$$

Hypergeometric distribution, $N = 20$, $N_1 = 5$, individual probabilities $\text{Prob}(x_1 = k_1 \mid X = K)$

x_1	$X=K$: 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	1	0.75	0.5526	0.3991	0.2817	0.1937	0.1291	0.0830	0.0511	0.0298	0.0163	0.0081	0.0036	0.0014	0.0004	0.0001					
1		0.25	0.3947	0.4605	0.4696	0.4402	0.3874	0.3228	0.2554	0.1916	0.1354	0.0894	0.0542	0.0293	0.0135	0.0048	0.0010				
2			0.0526	0.1316	0.2167	0.2935	0.3522	0.3874	0.3973	0.3831	0.3483	0.2980	0.2384	0.1761	0.1174	0.0677	0.0310	0.0088			
3				0.0088	0.0310	0.0677	0.1174	0.1761	0.2384	0.2980	0.3483	0.3831	0.3973	0.3874	0.3522	0.2935	0.2167	0.1316	0.0526		
4					0.0010	0.0048	0.0135	0.0293	0.0542	0.0894	0.1354	0.1916	0.2554	0.3228	0.3874	0.4402	0.4696	0.4605	0.3947	0.25	
5						0.0001	0.0004	0.0014	0.0036	0.0081	0.0163	0.0298	0.0511	0.0830	0.1291	0.1937	0.2817	0.3991	0.5526	0.75	1

Hypergeometric distribution, $N = 20$, $N_1 = 5$, cumulative probabilities $\text{Prob}(x_1 \leq k_1 \mid X = K)$

x_1	$X=K$: 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	1	0.75	0.5526	0.3991	0.2817	0.1937	0.1291	0.0830	0.0511	0.0298	0.0163	0.0081	0.0036	0.0011	0.0004	0.0001					
1		1	0.9474	0.8596	0.7513	0.6339	0.5165	0.4058	0.3065	0.2214	0.1517	0.0975	0.0578	0.0307	0.0139	0.0049	0.0010				
2			1	0.9912	0.9680	0.9274	0.8687	0.7932	0.7038	0.6045	0.5000	0.3955	0.2962	0.2068	0.1313	0.0726	0.0320	0.0088			
3				1	0.9990	0.9951	0.9861	0.9693	0.9422	0.9025	0.8483	0.7786	0.6935	0.5942	0.4835	0.3661	0.2487	0.1404	0.0526		
4					1	0.9999	0.9996	0.9986	0.9964	0.9919	0.9837	0.9702	0.9489	0.9170	0.8709	0.8063	0.7183	0.6009	0.4474	0.25	
5						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

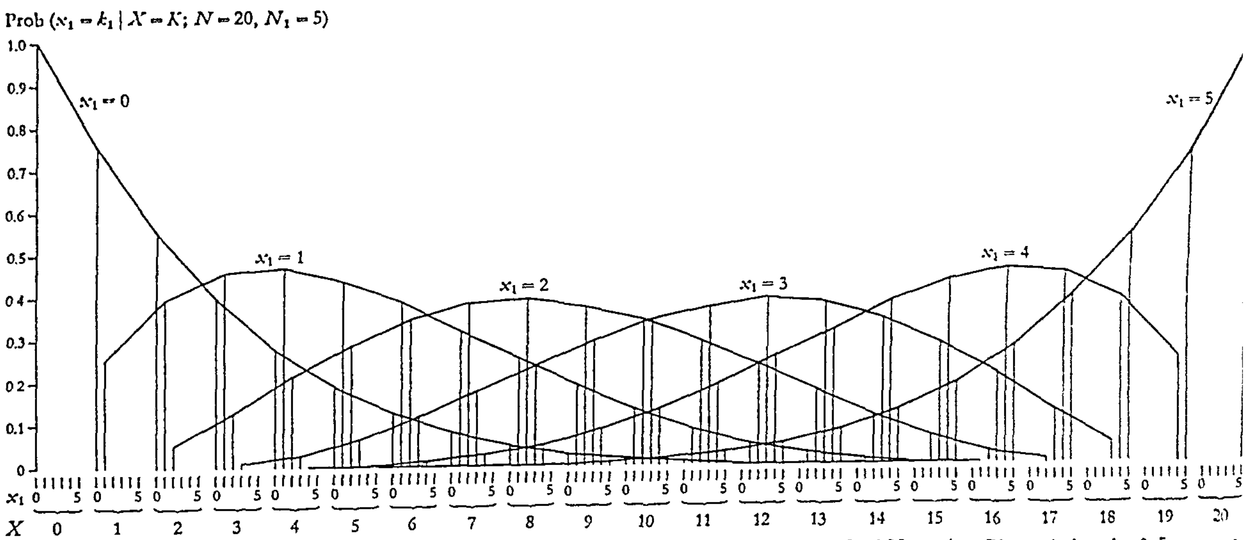


Fig. 47. Hypergeometric distribution. Graphical representation of all possible individual probabilities when N and N_1 are given. The vertical strokes 0–5 represent the probabilities $\text{Prob}(x_1 = 0, 1, \ldots, 5 \mid X = K)$. The curves link the probabilities $\text{Prob}(x_1 = k_1 \mid X = 0, 1, \ldots, 20)$.

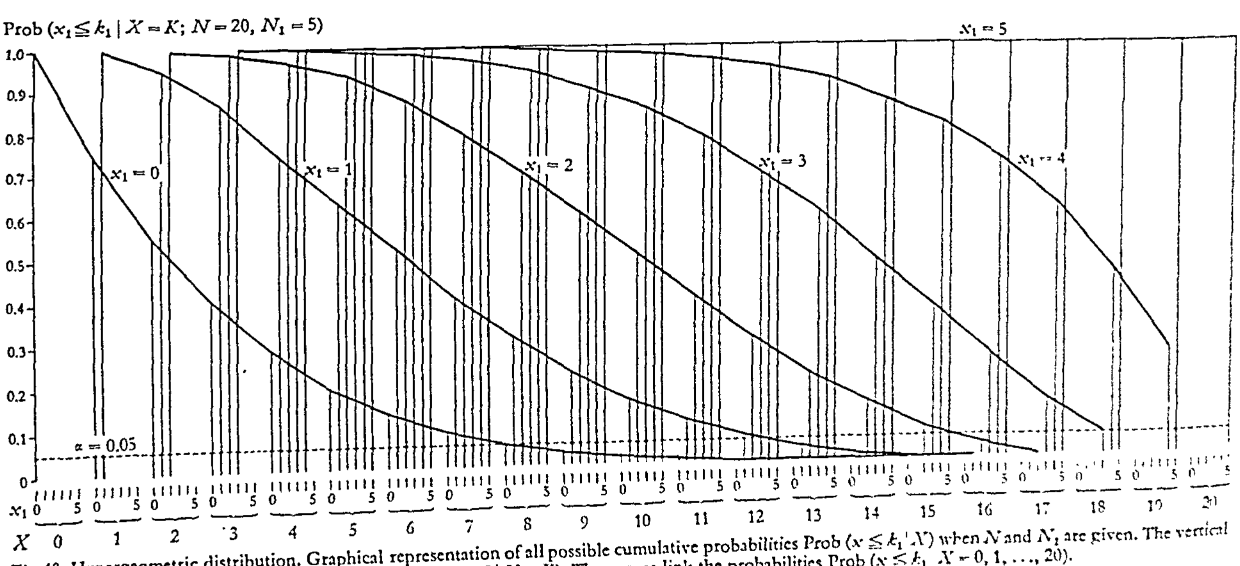


Fig. 48. Hypergeometric distribution. Graphical representation of all possible cumulative probabilities $\text{Prob}(x \leq k_1 \mid X)$ when N and N_1 are given. The vertical strokes 0–5 represent the probabilities $\text{Prob}(x_1 \leq 0, 1, \ldots, 5 \mid X = K)$. The curves link the probabilities $\text{Prob}(x \leq k_1 \mid X = 0, 1, \ldots, 20)$.

All the probabilities $f(x_1 \mid X, N=20, N_1=5)$ and cumulative probabilities $F(x_1 \mid X)$ are given in the tables on page 190, where the same probabilities are shown graphically in Figures 47 and 48

A check on calculations of this kind is provided by

$$\left.\begin{aligned} &\sum_{x_1=0}^{x_1=N_1} \text{Prob}(x_1 \mid X=K) = 1 & \text{(a)} \\ &\sum_{X=0}^{X=N-N_1+k_1} \text{Prob}(x_1 = k_1 \mid X) = \frac{N+1}{N_1+1} & \text{(b)} \end{aligned}\right\} \quad (809)$$

Figure 47 clearly demonstrates the symmetry of the relationship

$$\left.\begin{aligned} &\text{Prob}(x_1=k_1 \mid X=K) = \text{Prob}(x_1=N_1-k_1 \mid X=N-K) \\ &\text{hence} \\ &\text{Prob}(x_1 \leq k_1 \mid X=K) = \text{Prob}(x_1 \geq N_1-k_1 \mid X=N-k) \end{aligned}\right\} \quad (810)$$

22B. Parameters

The mean of x when X, N and N_1 are given is (putting $X/N = p$)

$$\mu_x = N_1 p \qquad (811)$$

and the variance is ($X/N = p$, $q = 1-p$)

$$\sigma_x^2 = N_1 pq \left(\frac{N-N_1}{N-1}\right) \qquad (812)$$

The variance of the hypergeometric distribution (N, N_1, p) is thus *smaller* than that of the binomial distribution (p, N_1) by the factor $(N-N_1)/(N-1)$

22C. The hypergeometric distribution and other distributions

[illegible] (813)

When $N_1/N < 0.1$ and N is fairly large the Poisson distribution $(\lambda = N_1 p)$ is a good approximation (814)

When $N_1 p \gtrsim 4$ (about), the normal distribution [(811), $\sqrt{(812)}$] is a good approximation, whence (815)

$$\left.\begin{aligned} &c_p = \frac{x_1 + \tfrac{1}{2} - (811)}{\sqrt{(812)}} & \text{(a)} \\ &c_{1-p} = \frac{x_1 - \tfrac{1}{2} - (811)}{\sqrt{(812)}} & \text{(b)} \end{aligned}\right\} \quad (816)$$

where $+\tfrac{1}{2}$ or $-\tfrac{1}{2}$ can be neglected when N is large

22D. Significance limits (fourfold table test)

(Cf remarks on page 123)

The significance limits given in the table on pages 109–123 meet the conditions (when N and N_1 are given)

$$\left.\begin{aligned} &\left.\begin{aligned} &\text{Prob}(x_1 \geq k_1 \mid X_l) \leq \alpha \\ &\text{Prob}(x_1 \geq k_1 \mid X_l + 1) > \alpha \end{aligned}\right\} \text{(a)} \\ &\text{and} \\ &\left.\begin{aligned} &\text{Prob}(x_1 \leq k_1 \mid X_r) \leq \alpha \\ &\text{Prob}(x_1 \leq k_1 \mid X_r - 1) > \alpha \end{aligned}\right\} \text{(b)} \end{aligned}\right\} \quad (817)$$

This form of presentation is preferred since it is also convenient in situations in which X is unknown (these do *not* correspond to the situation described at the start of section 22A, page 189)

The procedure for finding the upper level (817b) for $\alpha = 0.05$ is indicated in Figure 48 (horizontal broken line)

With large values of N, (817) can be satisfied approximately on the basis of (816) as follows[34]

When $N > 60$, $N_1 p \geq 4$, $N_1 p \geq 4$ (about), the $(1-2\alpha)$ significance limits for x_1 with X given can be obtained approximately as follows

$$x_l, x_r = N_1 p \mp \left[\tfrac{1}{2} + |c_\alpha| \sqrt{N_1 pq (N-N_1)/(N-1)}\right] \quad (819)$$

For p and q see (811)

23. Testing frequencies

23A. Samples from binomially distributed populations

[illegible] (820)

(*b*) Given *several* (m) *samples* of sizes $N_1, N_2, \ldots, N_i, \ldots, N_m$ in which the event E occurs $x_1, x_2, \ldots, x_i, \ldots, x_m$ times respectively. The following are calculated

$$p_i = \frac{x_i}{N_i}, \quad q_i = 1 - p_i, \quad \bar{p} = (\Sigma x_i)/(\Sigma N_i), \quad \bar{q} = 1 - \bar{p}$$

The x_i values are now transformed as follows in accordance with (764) and (766)

$$\left.\begin{aligned} &c_i = 2\left(\sqrt{(x_i+1)\bar{q}} - \sqrt{(N_i - x_i)\bar{p}}\right), \text{ when } p_i < \bar{p} \\ &\text{or} \\ &c_i = 2\left(\sqrt{x_i \bar{q}} - \sqrt{(N_i - x_i + 1)\bar{p}}\right), \text{ when } p_i > \bar{p} \end{aligned}\right\} \quad (821)$$

A comparison of the transformed data can be made by two methods

I Comparison on the basis of the extreme range (rapid test)

The difference between the highest and lowest values of c_i is the extreme range m, c_i being obtained from (821) (822)

[illegible]

For $m = 2$ (2 samples)

$$\left.\begin{aligned} &\text{one-tailed test} \quad \begin{cases} p_1 < p_2, \text{ if } p_1 - p_2 < 0 \ (\alpha) \\ p_1 > p_2, \text{ if } p_1 - p_2 > 0 \ (\alpha) \end{cases} \\ &\text{two-tailed test} \quad p_1 \neq p_2 \qquad (2\alpha) \end{aligned}\right\} \quad (823)$$

For $m > 2$ (more than 2 samples)

two-tailed test the samples do not all originate from the same population (824)

When $m = 2$ (2 samples), this test has the same power as the following χ^2 test. The range test is *not* recommended when $m > 10$.

II Comparison on the basis of χ^2

The squares of the c_i values are summed. Then the significance limit for the test statistic

Σc_i^2

is found from χ^2, pages 36–39, with degrees of freedom $\nu = m - 1$ (cf section 12B, page 166) (825)

[illegible]

$$\left.\begin{aligned} &X_l, X_r = \frac{N}{2k}\left(k + 2x_1 - N_1 - 1 \mp \sqrt{k^2 - \frac{2k}{N_1}\left[(x_1 \mp \tfrac{1}{2})^2 + (N_1 - x_1 \pm \tfrac{1}{2})^2\right] + (2x_1 - N_1 \mp 1)^2}\right) & \text{(a)} \\ &\text{or without continuity correction} \\ &X_l, X_r = \frac{N}{2k}\left(k + 2x_1 - N_1 \mp \sqrt{k^2 - \frac{2k}{N_1}\left[x_1^2 + (N_1 - x_1)^2\right] + (2x_1 - N_1)^2}\right) & \text{(b)} \end{aligned}\right\} \quad (818)$$

where in (a) and (b) $k = N_1 + (1 - N_1/N)c_\alpha^2$ $\quad c_\alpha^2 = \chi^2_\alpha$ for $\nu = 1$, $2\alpha = 1f_\alpha$, page 36

23B. Samples from multinomially distributed populations

Given are m samples of sizes $N_1, N_2, \ldots, N_i, \ldots, N_m$, in which the events $E_1, E_2, \ldots, E_j, \ldots, E_n$ occur $x_{1j}, x_{2j}, \ldots, x_{ij}, \ldots, x_{mn}$ times respectively, and

$$\left.\begin{array}{l}\sum_{j=1}^{n} x_{ij} = N_i, \sum_{i=1}^{m} x_{ij} = X_j \text{ and } \sum_{j=1}^{n} X_j = \sum_{i=1}^{m} N_i = N: \\ \begin{array}{ccccc|c} x_{11} & x_{12} & \ldots x_{1j} & \ldots x_{1n} & & N_1 \\ x_{21} & x_{22} & \ldots x_{2j} & \ldots x_{2n} & & N_2 \\ \vdots & \vdots & \vdots & \vdots & & \vdots \\ x_{i1} & x_{i2} & \ldots x_{ij} & \ldots x_{in} & & N_i \\ \vdots & \vdots & \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \ldots x_{mj} & \ldots x_{mn} & & N_m \\ \hline X_1 & X_2 & X_j & X_n & & N \end{array}\end{array}\right\} \quad (826)$$

The expected values $E_{ij} = N_i X_j / N$ of x_{ij} on the assumption of constant probabilities and independence are now calculated. The expected value of x_{11} (event 1 in sample 1), for example, is $N_1 X_1 / N$. With these expected values the following quotient is calculated for each observation x_{ij}:

$$\frac{(x_{ij} - E_{ij})^2}{E_{ij}} \quad \text{or} \quad \frac{x_{ij}^2}{X_j N_i} - 1 \qquad \text{(a)} \quad \text{(b)} \qquad (827)$$

and the values summed. The significance limit for the sum

$$\sum_1^n \sum_1^m \text{(827a)} \quad \text{or} \quad N \sum_1^n \sum_1^m \text{(827b)} \qquad (828)$$

is found from χ^2, pages 36–39, with degrees of freedom $\nu = (n-1)(m-1)$ and $2\alpha = 1 \int_r$. If the test statistic **(828)** *attains* or *exceeds* the significance limit, then interpretation **(825)** is valid.

23C. Samples from Poisson distributions

(*a*) *2 samples from two observation units of equal magnitude* $t_1 = t_2 = t$

Given are 2 samples with the *same* observation unit $t_1 = t_2 = t$, in which the event E occurs x_1 and x_2 times respectively.

The sums $x_1 + x_2 = N$ are calculated. The significance limits for x_1 and x_2 are then x_l and x_r of the table on pages 105 and 106 for $N = x_1 + x_2$. If x_1 and x_2 *attain* or *exceed* these limits (in an outward direction from ½ N), then the following interpretations may be made:

$$\left.\begin{array}{ll} \text{one-tailed test:} & \begin{cases} \lambda_1 < \lambda_2, \text{ if } x_1 \leq x_l \text{ (significance } \alpha) \\ \lambda_1 > \lambda_2, \text{ if } x_1 \geq x_r \text{ (significance } \alpha) \end{cases} \\ \text{two-tailed test:} & \lambda_1 \neq \lambda_2, \text{ if } x_1 \text{ and } x_2 \text{ attain or exceed} \\ & \text{(outwards) the levels } x_l \text{ and } x_r \\ & \text{(significance } 2\alpha) \end{array}\right\} \quad (829)$$

For samples with $x_1 + x_2 > 1000$ or $t_1 \neq t_2$ see (*b*) below.

(*b*) *Several samples from any number of observation units* t_i

Given are m samples from any number of observation units $t_1, t_2, \ldots, t_i, \ldots, t_m$ in which the event E occurs $x_1, x_2, \ldots, x_i, \ldots, x_m$ times. The following are calculated:

$$\lambda_i^* = \frac{x_i}{t_i} \text{ and } \bar{\lambda} = (\Sigma x_i)/(\Sigma t_i)$$

and the x_i values transformed into c_i values as follows in accordance with **(794)** and **(796)**:

$$\left.\begin{array}{l} c_i = 2\left(\sqrt{x_i + 1} - \sqrt{t_i \bar{\lambda}}\right), \text{ if } \lambda_i^* < \bar{\lambda} \\ c_i = 2\left(\sqrt{x_i} - \sqrt{t_i \bar{\lambda}}\right), \text{ if } \lambda_i^* > \bar{\lambda} \end{array}\right\} \quad (830)$$

Comparison of these transformed data and their interpretations are as in section 23A (b), I and II, with $\bar{\lambda}$ and λ_i^* in place of $\bar{p}$ and p_i.

(*c*) *Confidence limits for the increase in frequency of a rare event*[35]

Given are two samples of sizes N_1 and N_2 in which the fairly *rare* event E occurs with a relative frequency of $p_1 = x_1/N_1$ and $p_2 = x_2/N_2$ respectively. *The samples should be so numbered that* $p_1 < p_2$. The estimate of the proportionate *increase* in relative frequency from sample 1 to sample 2 is then

$$Proc_{1\to 2} = \frac{p_2 - p_1}{p_1} \qquad (831)$$

with the $(1 - 2\alpha)$ confidence limits for $\boldsymbol{Proc}_{1\to 2}$

$$k\left(\frac{1}{p_r} - 1\right) - 1 < \boldsymbol{Proc}_{1\to 2} < k\left(\frac{1}{p_l} - 1\right) - 1 \qquad (832)$$

where $k = N_1/N_2$ and p_r and p_l are obtained from the ta[ble of] confidence limits for $\boldsymbol{p}$ of the binomial distribution on page[s] 103 for $N = x_1 + x_2$ and $x = x_1$. **(831)** and **(832)** are conver[ted to] percentages by multiplying by 100. **(832)** can also be calcula[ted in] this way when only the *ratio* N_1/N_2 and the absolute numb[ers x_1] and x_2 are known. *Interpretation:* When the left limit of (8[32] is] zero, then no increase in frequency has occurred.

24. Rank tests

24A. Ranking

(*a*) *By magnitude* (continuous distributions). Given are samples 1 and 2 with the x_1 values 1.06, 1.53, 1.68, 1.68, 1.69[, 1.69] and the x_2 values 1.30, 1.55, 1.69, 1.80. These values are rank[ed as] follows:

$$\left.\begin{array}{lcccccccccc} x_1 & 1.06 & & 1.53 & & 1.68 & 1.68 & & 1.69 & 1.69 & \\ x_2 & & 1.30 & & 1.55 & & & 1.69 & & & 1.80 \\ O_{1,2} & 1 & 2 & 3 & 4 & 5 & 6 & \underbrace{8 \quad 8 \quad 8}_{= (7+8+9)/3} & & & 10 \end{array}\right\}$$

With ties [cf. **(346)**], the procedure is as in **(833)**: tied values *within* a sample receive *successive* rank numbers, those *between* the samples the *mean* of the two rank numbers at the position concerned. (

In the above example, the rank numbers O_1 of the x_1 values are $O_1 = 1, 3, 5, 6, 8$ and 8, and their sum $T_1 = \Sigma O_1 = 31$. (

With *paired observations*, the n pair differences d_i are calculated as in section 16D, page 173, with all d_i values equal to zero ignored and N reduced accordingly. The *absolute values* of these differences are then ranked and either the rank numbers of all negative differences summed to give T_- or those of all positive differences summed to give T_+. (8

(*b*) *By order in a series* (discrete distributions). If in a series of N trials the event E occurs once each in the 2nd, 3rd, 8th and 13th trials, in all N_1 times (for example 4 times), then $O_E = 2, 3, 8$ and 13 respectively and the sum of the O_E numbers $= T_E = 26$. (8

24B. The Wilcoxon test for two samples[36, 37]

Given are two samples from *continuous* distributions of *any* fo[rm] with means μ_1 and μ_2 respectively. These are so numbered t[hat] $N_1 \leq 25$ and $N_2 \leq 50$. The x_1 values are now ranked as in (8[33]) and **(834)** to give the sum T_1 of **(835)**.

The significance limits for T_1 are given in the tables on pages 124–127. If T_1 *attains* the significance levels or *exceeds them in the outward direction* from its expected value, then this may be regarded as evidence that

$$\left.\begin{array}{ll} \text{one-tailed test:} & \begin{cases} \mu_1 < \mu_2, \text{ if } T_1 \leq T_l \ (\leq \alpha) \\ \mu_1 > \mu_2, \text{ if } T_1 \geq T_r \ (\leq \alpha) \end{cases} \\ \text{two-tailed test:} & \mu_1 \neq \mu_2, \text{ if } T_1 \leq T_l \text{ or } T_1 \geq T_r \ (\leq 2\alpha) \end{array}\right\} \quad (83$$

Cf. also section 9C, page 157.

Under the null hypothesis, the expectation $\boldsymbol{T}_1$ of the estima[tor] T_1 is

$$\left.\begin{array}{lr} \boldsymbol{T}_1 = N_1 (N_1 + N_2 + 1)/2 \quad \text{or} & \text{(a)} \\ 6\,\boldsymbol{T}_1 = 3\,N_1 (N_1 + N_2 + 1) & \text{(b)} \end{array}\right\} \quad (83$$

$$\left.\begin{array}{lr} \text{and the variance } \sigma_{T_1}^2 = N_2 \boldsymbol{T}_1 / 6 \quad \text{or} & \text{(a)} \\ \sigma_{6T_1}^2 = 6\,N_2 \boldsymbol{T}_1 & \text{(b)} \end{array}\right\} \quad (84$$

For samples outside the scope of the tables the following tes[t] quotient can be used

$$(T_1 - \boldsymbol{T}_1) / \sqrt{\sigma_{T_1}^2} \text{ or } (6\,T_1 - 6\,\boldsymbol{T}_1) / \sqrt{\sigma_{6T_1}^2} \qquad \text{(a)} \quad \text{(b)} \qquad (841$$

Significance limit t_α, page 28.

24C. The Wilcoxon test for pair differences[37]

(Cf. section 9C, page 158)

The sum T_- is calculated in accordance with **(836)**. The number o[f] ranked pair differences is denoted by n (all zero values are ignored).

Significance limits for the sum T_- are given in the table on page 128. If the differences have been calculated as $d_i = x_{1i} - x_{2i}$ and the sum T_- *attains* the significance limits or *exceeds them in the outward direction* from the expected value of T_-, then it follows that

$$\left.\begin{array}{ll} \text{one-tailed test.} & \begin{cases} \mu_1 > \mu_2, \text{ when } T_- \leqq T_l\ (\leqq \alpha) \\ \mu_1 < \mu_2, \text{ when } T_- \geqq T_r\ (\leqq \alpha) \end{cases} \\ \text{two-tailed test} & \mu_1 \neq \mu_2, \text{ when } T_- \leqq T_l \text{ or } T_- \geqq T_r\ (\leqq 2\alpha) \end{array}\right\} \quad (842)$$

Under the null hypothesis, the expectation $\boldsymbol{T}_-$ of the estimate T_- is

$$\boldsymbol{T}_- = n(n+1)/4 \quad (843)$$

and the variance is

$$\sigma^2_{T_-} = (2n+1)\,\boldsymbol{T}/6 \quad (844)$$

For samples outside the scope of the tables the following test quotient can be used,

$$(T_- - \boldsymbol{T}_-)/\sqrt{\sigma^2_{T_-}} \quad (845)$$

Significance limit t_α, page 28

24D. Haldane's test for chance order in series[38]

[illegible]

question whether the mortality in, or success of, a particular operation in the *same* hospital is increasing or decreasing, and so on. The test was developed by HALDANE for such problems independently of WILCOXON

(*a*) *Investigation of a series.* T_E is calculated as in (837). N_1 is the number of trials (births, operations, etc.) in which the event E has occurred. N_2 is $N - N_1$, where N is the total number of trials in the series being investigated.

The significance limits for T_E are the same as those in section 24B, the interpretation, however, is completely different. *One-tailed test.* If T_E attains or exceeds the *left* limit, then the frequency *decreases* with increasing lateness in the series, if it attains or exceeds the *right* limit, the frequency increases. *Two-tailed test.* The order has an influence on the frequency. (846)

If all the events in the series cannot be specified, the following sequence, for example, may arise

Trial	2	3	4	5	6	7	8	9	10	11	12
	+	+	?	−	+	?	+	−	+	?	+
O_E				5				9			
$O_?$			4			7				11	

(847)

and the tables on pages 124–127 can no longer be used. In such cases the test criterion (841b) is used, with

$$\left.\begin{array}{lll} 6\,T_E & = 6\,\Sigma\,O_E & \text{(a)} \\ 6\,\boldsymbol{T}_E & = 6\,N_1 A/N & \text{(b)} \\ \sigma^2_{T_E} & = 36\,N_1 N_2 (NB - A^2)/N^2(N-1) & \text{(c)} \\ A & = N(N+1)/2 - \Sigma\,O_? & \text{(d)} \\ B & = N[1 + N(2N+3)]/6 - \Sigma\,O_?^2 & \text{(e)} \end{array}\right\} \quad (848)$$

If all the events are specified but the sample exceeds the scope of the table, then equations (839b) and (840b) can be used in conjunction with (841b)

(*b*) *Investigation of several series as samples from the same population.* The successive offspring of 1, 2, 3, ..., i, ..., m mothers, for example, are to be investigated in respect of a childhood disease that appears to be commoner among later births.

The test criterion (841b) is used, with

$$\left.\begin{array}{l} 6\,T = \Sigma\,6\,T_i \\ 6\,\boldsymbol{T} = \Sigma\,6\,\boldsymbol{T}_i \\ \sigma^2_T = \Sigma\,\sigma^2_{T_i} \end{array}\right\} \quad (849)$$

$6\,\boldsymbol{T}_i$ and $\sigma^2_{T_i}$ are calculated from (839b) and (840b) or from (848b) and (848c) respectively, according to whether all the events in the series i are specified or not.

24E. The maximum test for pair differences[21,39]

(This name was proposed by E. WALTER. The test is described here since it is also useful for assessing series, though by a method different to that of the WILCOXON test.)

With paired observations from *continuous* populations of *any* form the pair differences d_i are calculated as in section 16D, page 173. All zero values of d_i are excluded and the remainder arranged in the order of their *absolute magnitudes*. If two differences of equal absolute magnitude but opposite sign appear, then in order to be on the safe side these are so arranged that any runs of the same sign are as small as possible. The k differences with the highest absolute magnitude and the *same* sign are then counted.

The significance probability for a difference between the two series of measurements (two-tailed test) is then $2\alpha = (\tfrac{1}{2})^{k-1}$, that is,

$k =$	$2\alpha =$	$\alpha =$
5	0.0625 ~ 0.1	0.03125 ~ 0.05
6	0.03125 ~ 0.05	0.015625 ~ 0.02
8	0.0078125 ~ 0.01	0.00390625 ~ 0.005
11	0.0009725 ~ 0.001	0.00048625 ~ 0.0005

(850)

Example 73. The series +3.2, +2.0, +1.0, +1.0, +0.7, +0.5, −0.3, +0.3 (note the awkward position of −0.3) results in a significance probability of $2\alpha \sim 0.05$

25. Testing for non-randomness

[illegible]

25A. The mean-square successive difference[40]

The mean-square successive difference δ^2 is defined as

$$\delta^2 = \frac{1}{N-1}\sum_{1}^{N-1}(x_{i+1} - x_i)^2;\ N = \text{size of the sample} \quad (851)$$

If the sample originates from a normally distributed population, then

$$\text{Expectation of } \delta^2 = 2\sigma^2 \quad (852)$$

$\delta^2/2$ is thus an unbiased estimate of σ^2 with

$$\text{Efficiency} = 2/3\,[1 + 1/(3N - 4)] \quad (853)$$

For $N = 2$, the efficiency is therefore unity; for $N \to \infty$ (asymptotically) it is $\tfrac{2}{3}$.

Since the mean-square successive difference is calculated on the basis of the succe[illegible]

$$\text{The ratio } \eta = \frac{\delta^2}{s^2} = \frac{\sum_{1}^{N-1}(x_{i+1} - x_i)^2}{\sum_{1}^{N}(x_i - \bar{x})^2} \quad (854)$$

is therefore an indication of a possible non-random influence on the mean of a *normally distributed* population.

Significance limits for η are given [illegible] (855)

The approximate limits ($N > 60$) in the table on page 58 have been calculated from

$$\eta_l, \eta_r = 2 \mp 2\,|t_\alpha|\,\sqrt{\frac{N-2}{(N-1)(N+1)}} \quad (856)$$

with empirical correction at the transition from exact to approximate values

25B Serial correlation[41]

Given [illegible]

known as the lag. For $i + h > N$, $x_{i+h} = x_{i+h-N}$ in the *cyclic* definition. For further details the reader is referred to the literature[41,42].

With the cyclic definition, serial correlation is a sensitive instrument for revealing periodic influences on a population (or sample when the population is stable).

A measure of the serial correlation with lag h is the serial correlation coefficient $\mathcal{R}_h$. Its estimate is

$$R_h = \frac{\Sigma x_i x_{i+h} - \bar{x}\,\Sigma x_i}{\Sigma (x_i - \bar{x})^2} \tag{857}$$

As with other correlation coefficients, its value lies between -1 and $+1$.

The right-hand table on page 58 gives the significance limits for $R_h = 0$ (when $h = 1$) on the assumption that the samples are random samples from a normally distributed population. The approximate limits ($N > 75$) have been calculated from

$$R_l, R_r = \frac{-1 \mp |r_\alpha| \sqrt{N-2}}{N-1} \tag{858}$$

(N = number of values x_i included in the calculation)

with empirical correction at the transition from exact to approximate values. With this approximation the user remains on the safe side.

For lags other than 1 the same levels can be used, provided that h and N do not possess a common factor. The latter is always the case when N is a prime number. In practice these conditions can be met by deleting one or more individual sample values.

25C. Runs up and down[43,44]

If $x_1, x_2, \ldots, x_i, \ldots, x_N$ are individual sample values from a *continuous* population of *any* form, then a run up of length 1 is defined as the sequence $x_i \to x_{i+1}$ when $x_{i+1} - x_i > 0$. For runs down, $x_{i+1} - x_i < 0$. A sequence of three runs up of length 1 is called a run up of length 3, and so on.

If the sample is a random one not subject to cyclic or constant non-random influences, then the runs up and down should present a random picture, that is to say, there should be no regular runs and not too many long ones or too few short ones.

Runs up and down can be tested by means of the table at the foc of page 130. Thus a run of length 5 in a sample of size $N = 9$, fo example, is not likely to be random ($\alpha = 0.01$). In the same way, sample of size $N = 12$ is not likely to be a random sample when n run of length 2 is present (significance probability $1 - 0.99 = 0.01$)

The number I ($l \mid N$) of runs up and down of length l and th number I ($l + \mid N$) of runs of length l and *longer* can be regarded a normally distributed from $N = 20$ onwards. This can be tested b means of the quotient

$$(I - \mathcal{I}) / \sqrt{\sigma_I^2}\text{; significance level } |r_\alpha|\text{, page 28} \tag{859}$$

The expected value $\mathcal{I}$ and the variance σ_I^2 are functions of N; appropriate formulae are to be found in the literature[43]. To some extent their calculation is a tedious operation. The two tables (860) and (861) above give values up to the length usually found in practice; they also show clearly how σ^2 for greater lengths converges rapidly toward the expected value $\mathcal{I}$. It follows from (789) that the distribution of runs up and down very closely approximates, for runs of greater length, to a POISSON distribution (or to approximations to a POISSON distribution) with $\lambda = \mathcal{I}$.

25D. Runs above and/or below the median[45]

Runs above and/or below the median can be tested by means of the table on page 130, where a brief explanation of the method will be found.

25E. Runs in samples from binomially distributed populations in which the probabilities p and q are unknown

The definition is as follows:

(Time)	1	2	3	4	5	6	7	8	9	10
Series (I)	A	B	A	A	A	B	B	A	B	A
Series (II)	A	B	A	B	A	A	B	A	B	A
Series (III)	A	A	A	A	A	A	B	B	B	B

Each of the series (I), (II), (III) has a size $N = 10$ and contains $N_1 = 4$ B's and $N_2 = 6$ A's (provided that $N = N_1 + N_2 < 40$, the smaller number is denoted by N_1). In these series the underscored

Expected value $\mathcal{I}$ ($l \mid N$) and variance of runs up and down of length l

(860)

Length	Expected value $\mathcal{I}$ ($l \mid N$): Exact $\mathcal{I}(l \mid N) = aN - b$		Asymptotic $\mathcal{I}(l \mid N \to \mathcal{I}(1 + \mid N) \times c$ $(N \to \infty)$	Variance $\sigma_I^2 = d \times \mathcal{I}(l \mid N) + e$		Remarks
l	a	b	c	d	e	Note
1	$4.1\dot{6} \times 10^{-1}$	$-8.\dot{3} \times 10^{-2}$	6.25×10^{-1}	$1.01\dot{6}$	$-0.397\dot{2}$	– for b and e
2	$1.8\dot{3} \times 10^{-1}$	$2.\dot{3} \times 10^{-1}$	2.75×10^{-1}	0.614550	−0.01943342	– for e
3	$5.2\dot{7} \times 10^{-2}$	$1.30\dot{5} \times 10^{-1}$	$7.91\dot{6} \times 10^{-2}$	0.794215	0.00678218	
4	$1.15079365 \times 10^{-2}$	$4.12698413 \times 10^{-2}$	$1.72619048 \times 10^{-2}$	0.935800	0.00083924	
5	$2.03373016 \times 10^{-3}$	$9.47420634 \times 10^{-3}$	$3.05059524 \times 10^{-3}$	0.985361	0.00004629	
6	$3.03130511 \times 10^{-4}$	$1.73059965 \times 10^{-3}$	$4.54695767 \times 10^{-4}$	0.997338	0.00000156	
7	$3.91313933 \times 10^{-5}$	$2.63999118 \times 10^{-4}$	$5.86970899 \times 10^{-5}$	0.999595	0.00000004	
8	$4.45927529 \times 10^{-6}$	$3.46721180 \times 10^{-5}$	$6.68891294 \times 10^{-6}$	0.999947	0.00000000	
9	$4.55113302 \times 10^{-7}$	$4.00416199 \times 10^{-6}$	$6.82669953 \times 10^{-7}$	0.999994	0.00000000	
10	$4.20746948 \times 10^{-8}$	$4.13038607 \times 10^{-7}$	$6.31120422 \times 10^{-8}$	0.999999	0.00000000	

Expected value $\mathcal{I}$ ($l + \mid N$) and variance of runs up and down of length l and longer

(861)

Length	Expected value $\mathcal{I}$ ($l + \mid N$): Exact $\mathcal{I}(l + \mid N) = aN - b$		Asymptotic $\mathcal{I}(l + \mid N) \to \mathcal{I}(1 + \mid N) \times c$ $(N \to \infty)$	Variance $\sigma_I^2 = d \times \mathcal{I}(l + \mid N) + e$		Remarks
$l+$	a	b	c	d	e	Note
1	$6.\dot{6} \times 10^{-1}$	$3.\dot{3} \times 10^{-1}$	1	$0.2\dot{6}$	$-0.2\dot{3}$	– for e
2	$2.\dot{5} \times 10^{-1}$	$4.1\dot{6} \times 10^{-1}$	3.75×10^{-1}	$0.31\dot{6}$	$0.07\dot{2}$	
3	$6.\dot{6} \times 10^{-2}$	$1.8\dot{3} \times 10^{-1}$	1×10^{-1}	0.710847	0.01729497	
4	$1.3\dot{8} \times 10^{-2}$	$5.2\dot{7} \times 10^{-2}$	$2.08\dot{3} \times 10^{-2}$	0.917857	0.00147817	
5	2.38095×10^{-3}	$1.15079365 \times 10^{-2}$	$3.57142857 \times 10^{-3}$	0.982145	0.00007053	
6	$3.47\dot{2} \times 10^{-4}$	$2.03373016 \times 10^{-3}$	$5.208\dot{3} \times 10^{-4}$	0.996871	0.00000220	
7	$4.40917108 \times 10^{-5}$	$3.03130511 \times 10^{-4}$	$6.61375661 \times 10^{-5}$	0.999535	0.00000005	
8	$4.96031746 \times 10^{-6}$	$3.91313933 \times 10^{-5}$	$7.44047619 \times 10^{-6}$	0.999940	0.00000000	
9	$5.01042167 \times 10^{-7}$	$4.45927529 \times 10^{-6}$	$7.51563251 \times 10^{-7}$	0.999993	0.00000000	
10	$4.59288653 \times 10^{-8}$	$4.55113302 \times 10^{-7}$	$6.88932980 \times 10^{-8}$	0.999999	0.00000000	
11	$3.854170\dot{5}2 \times 10^{-9}$	$4.20746948 \times 10^{-8}$	$5.78125578 \times 10^{-9}$	0.999999	0.00000000	

rs in each case form a run. The total number of runs I is 7 in

) If the left limit is *attained* or *exceeded*, then
is significantly less than $\mathbf{I}$ (significance probability α) or differs significantly from $\mathbf{I}$ (significance probability 2α)

b) If the right limit is *attained* or *exceeded*, then
is significantly greater than $\mathbf{I}$ (significance probability α) or differs significantly from $\mathbf{I}$ (significance probability 2α)

c) If I lies between the limits and *attains neither*, then the null pothesis cannot be rejected

For N_1 and N_2 values outside the scope of the table, the test otient (859) can be used in conjunction with (868a) and (848b).

pected values and variances

for the number of runs of length l of the event 1 that has occurred otal of N_1 times (N_2 = number of events 2, $N = N_1 + N_2$)

$$\left.\begin{aligned} &\mathbf{I}_1(l \mid N_1, N_2) = N_2(N_2+1)\frac{N_1!\,(N-l-1)!}{N!\,(N_1-l)!} && \text{(a)}\\ &\sigma^2 = \mathbf{I}\left[1-\mathbf{I}+N_2(N_2-1)\frac{(N-2l-2)!\,(N_1-l)!}{(N-l-1)!\,(N_1-2l)!}\right] && \text{(b)}\end{aligned}\right\}(862)^{46}$$

nd asymptotically for higher values of N

$$\left.\begin{aligned} &\mathbf{I}_1(l \mid N_1, N_2) = Np^lq^2 && \text{(a)}\\ &\sigma^2 = \mathbf{I}\left\{1-\frac{\mathbf{I}}{N}\left[\frac{l^2}{p}+\frac{2}{q}-(l+1)^2\right]\right\} && \text{(b)}\end{aligned}\right\}\begin{aligned}p &= N_1/N\\ q &= 1-p\end{aligned}\quad(863)^{46}$$

for the number of runs of length l and *longer* of the event 1

$$\left.\begin{aligned} &\mathbf{I}_1(l+ \mid N_1, N_2) = (N_2+1)\frac{N_1!\,(N-l)!}{N!\,(N_1-l)!} && \text{(a)}\\ &\sigma^2 = \mathbf{I}\left[1-\mathbf{I}+N_2\frac{(N-2l)!\,(N_1-l)!}{(N-l)!\,(N_1-2l)!}\right] && \text{(b)}\end{aligned}\right\}(864)^{46}$$

nd asymptotically

$$\left.\begin{aligned} &\mathbf{I}_1(l+ \mid N_1, N_2) = Np^lq && \text{(a)}\\ &\sigma^2 = \mathbf{I}\left\{1-\frac{\mathbf{I}}{N}\left[\frac{l^2q}{p}+\frac{1}{q}\right]\right\} && \text{(b)}\end{aligned}\right\}\ p \text{ and } q \text{ as in (863)}\quad(865)^{46}$$

– for the total number of all runs of the event 1

$$\left.\begin{aligned} &\mathbf{I}_1(\text{total} \mid N_1, N_2) = \mathbf{I}_1(1+ \mid N_1, N_2) = \frac{N_1(N_2+1)}{N} && \text{(a)}\\ &\sigma^2 = \frac{\mathbf{I}(\mathbf{I}-1)}{N-1} && \text{(b)}\end{aligned}\right\}(866)^{47}$$

and asymptotically

$$\left.\begin{aligned} &\mathbf{I}_1(\text{total} \mid N_1, N_2) = \mathbf{I}(1+ \mid N_1, N_2) = Npq && \text{(a)}\\ &\sigma^2 = \mathbf{I}^2/N && \text{(b)}\end{aligned}\right\}\ p \text{ and } q \text{ as in (863)}\quad(867)^{46}$$

– for the total number of all runs of events 1 and 2

$$\left.\begin{aligned} &\mathbf{I}_{1+2}(\text{total} \mid N_1, N_2) = \frac{2N_1N_2}{N}+1 && \text{(a)}\\ &\sigma^2 = \frac{(\mathbf{I}-1)(\mathbf{I}-2)}{N-1} && \text{(b)}\end{aligned}\right\}(868)^{48}$$

and asymptotically

$$\left.\begin{aligned} &\mathbf{I}_{1+2}(\text{total} \mid N_1, N_2) = 2Npq && \text{(a)}\\ &\sigma^2 = \mathbf{I}^2/N && \text{(b)}\end{aligned}\right\}\ p \text{ and } q \text{ as in (863)}\quad(869)^{48}$$

The total number of all runs of the event 1 can be tested exactly (within the scope of the tables on pages 109–123) by means of the fourfold table test[47]

$$\left.\begin{array}{cc|c} I_1 & N_1 - I_1 & N_1\\ N_2+1-I_1 & I_1 - 1 & N_2\\ \hline N_2+1 & N_1-1 & N\end{array}\right\}\quad(870)$$

25F The Wald-Wolfowitz test[48]

Given are two samples from *continuous* populations of *any* form. These are ranked as in (833) and the total number of all runs (a run being defined as the occurrence of *successive* rank numbers in a sample) counted. Testing is carried out by means of the table on page 129 (cf. section 25E) or, for samples outside the scope of th table, by means of the test quotient (859) in conjunction with (868 and b) or (869a and b).

Example 74. Ranking and determination of runs (1, 2, ... is he a rank order):

Sample 1	1.55	1.58	1.70		1.92			2.20	2.21		
Sample 2				1.91		1.93	2.00			2.30	2.4
$O_{1,2}$	1	2	3	4	5	6	7	8	9	10	1
Run 1 and 2		1		1	1	1		1		1	

Total runs 6, $N = 11$, $N_1 = 6$, $N_2 = 5$

If the total number of runs *attains* or *passes* the *left* limit (on this limit can be used in this test), then the samples do not origina from the same population (significance probability 2α).

25G. Runs in samples from binomially distributed populatio in which the probabilities p and q are known

Expected values and variances

– for the number of runs of length l of the event 1 the probabil of whose occurrence is p ($q = 1 - p$)

$$\left.\begin{aligned} &\mathbf{I}_1(l=N \mid N,p) = p^N && \text{(a)}^{49}\\ &\sigma^2 = \mathbf{I}(1-\mathbf{I}) && \text{(b)}^{50}\\ &\mathbf{I}_1(l \le N-1 \mid N,p) = p^lq\,[(N-l-1)\,q+2] && \text{(c)}^{49}\\ &\sigma^2 = \mathbf{I}(1-\mathbf{I}) + \varphi(N,l) && \text{(d)}^{50}\\ &\text{where}\\ &\varphi(N,l) = 0;\ 2l \ge N && \text{(e)}^{50}\\ &\varphi(N,l) = p^{2l}q^2[6+6(N-2l-2)\,q + (N-2l-2) \times (N-2l-3)\,q^2],\ 2 \le 2l \le N-2 && \text{(f)}^{50}\\ &\varphi\left(N,\frac{N-1}{2}\right) = 2p^{N-1}q,\ N \text{ odd} && \text{(g)}^{50}\end{aligned}\right\}\ (8$$

and asymptotically when $N - l \to \infty$

$$\left.\begin{aligned} &\mathbf{I}_1(l \mid N,p) = Np^lq^2 && \text{(a)}^{49}\\ &\sigma^2 = \mathbf{I}\left\{1-p^lq^2\left[2\left(l-\frac{p}{q}\right)+1\right]\right\} && \text{(b)}^{46}\end{aligned}\right\}\ (8$$

– for the number of runs of length l and *longer*

$$\left.\begin{aligned} &\mathbf{I}_1(l+ \mid N,p) = p^l[(N-l)\,q+1] && \text{(a)}^{49}\\ &\sigma^2 = \mathbf{I}(1-\mathbf{I}) + \psi(N,l) && \text{(b)}^{50}\\ &\text{where}\\ &\psi(N,l) = 0,\ 2l \ge N && \text{(c)}^{50}\\ &\psi(N,l) = p^{2l}q\,(N-2l)\,[2+(N-2l-1)\,q],\ 2 \le 2l \le N && \text{(d)}^{50}\end{aligned}\right\}\ ($$

and asymptotically when $N - l \to \infty$

$$\left.\begin{aligned} &\mathbf{I}_1(l+ \mid N,p) = Np^lq && \text{(a)}^{49}\\ &\sigma^2 = \mathbf{I}[1-p^lq\,(2l+1)] && \text{(b)}^{46}\end{aligned}\right\}\ ($$

– for the total number of runs of the event 1

$$\left.\begin{aligned} &\mathbf{I}_1(\text{total} \mid N,p) = p\,[(N-1)\,q+1] && \text{(a)}^{49}\\ &\sigma^2 = \mathbf{I}(1-\mathbf{I}) + (N-2)\,p^2q\,[(N-3)\,q+2] && \text{(b)}^{46}\end{aligned}\right\}\ ($$

and asymptotically

$$\left.\begin{aligned} &\mathbf{I}_1(\text{total} \mid N,p) = Npq && \text{(a)}\\ &\sigma^2 = \mathbf{I}(1-3pq) && \text{(b)}\end{aligned}\right\}(87$$

– for the total number of runs of events 1 and 2

$$\left.\begin{aligned} &\mathbf{I}_{1+2}(\text{total} \mid N,p) = 2(N-1)\,pq+1 && \text{(a)}\\ &\sigma^2 = 2pq\{2[N-(3N-5)\,pq]-3\} && \text{(b)}\end{aligned}\right\}(87$$

and asymptotically

$$\left.\begin{aligned} &\mathbf{I}_{1+2}(\text{total} \mid N,p) = 2Npq && \text{(a)}\\ &\sigma^2 = \mathbf{I}(2-3pq) && \text{(b)}\end{aligned}\right\}(87$$

25H. Runs in samples from multinomially distributed populations

(a) The probabilities $p_1, p_2, \ldots, p_i, \ldots, p_k$ are unknown

Expected values and variances

– for the total number of runs of the event i that has occurr total of N_i times

$$\left.\begin{array}{ll} \boldsymbol{I}_i(\text{total} \mid N_i, N) = \dfrac{N_i(N - N_i + 1)}{N} & \text{(a)} \\ \sigma^2 \qquad\qquad = \dfrac{\boldsymbol{I}(\boldsymbol{I}-1)}{N-1} & \text{(b)} \end{array}\right\} \quad (879)^{46}$$

and asymptotically

$$\left.\begin{array}{ll} \boldsymbol{I}_i(\text{total} \mid N_i, N) = Np_i(1-p_i) \\ \sigma^2 \qquad\qquad = \boldsymbol{I}^2/N \end{array}\right\} p_i = \frac{N_i}{N} \quad \begin{array}{l}\text{(a)}\\ \text{(b)}\end{array} \quad (880)^{46}$$

– for the total number of runs of all events

asymptotically

$$\left.\begin{array}{ll} \boldsymbol{I}(\text{total}, N) = N(1 - \sum_1^k p_i^2) \\ \sigma^2 \qquad = N[\Sigma p_i^2 - 2\Sigma p_i^3 + (\Sigma p_i^2)^2] \end{array}\right\} p_i \text{ as in (880)} \quad \begin{array}{l}\text{(a)}\\ \text{(b)}\end{array} \quad (881)^{46}$$

When $N_1 = N_2 = \cdots = N_k = N_0$, (881) becomes

$$\left.\begin{array}{ll} \boldsymbol{I}(\text{total}) = N(1-p) \\ \sigma^2 \qquad = p\boldsymbol{I} \end{array}\right\} p = 1/k;\ N = kN_0 \quad \begin{array}{l}\text{(a)}\\ \text{(b)}\end{array} \quad (882)$$

(*b*) *The probabilities p_i are known*

p_i is the probability that the event i will occur.

Expected values and variances

– for the total number of runs of the event i

$$\left.\begin{array}{ll} \boldsymbol{I}_i(\text{total} \mid N, p_i) = p_i[(N-1)(1-p_i)+1] & \text{(a)} \\ \sigma^2 \qquad = Np_i(1 - 4p_i + 6p_i^2 - 3p_i^3) + \\ \qquad\qquad + p_i^2(3 - 8p_i + 5p_i^2) & \text{(b)} \end{array}\right\} (883)^{46}$$

[Formula (883) is identical with (875) when, in the latter, p is replaced by p_i]

and asymptotically

$$\left.\begin{array}{ll} \boldsymbol{I}_i(\text{total} \mid N, p_i) = Np_i(1-p_i) & \text{(a)} \\ \sigma^2 \qquad = \boldsymbol{I}[1 - 3p_i(1-p_i)] & \text{(b)} \end{array}\right\} (884)^{46}$$

– for the total number of runs of all events

asymptotically

$$\left.\begin{array}{ll} \boldsymbol{I}(\text{total}) = N(1 - \Sigma p_i^2) & \text{(a)} \\ \sigma^2 \qquad = N[\Sigma p_i^2 + 2\Sigma p_i^3 - 3(\Sigma p_i^2)^2] & \text{(b)} \end{array}\right\} (885)^{46}$$

When $p_1 = p_2 = \cdots p_k = p = 1/k$, (885) becomes

$$\left.\begin{array}{ll} \boldsymbol{I}(\text{total}) = N(1-p) & \text{(a)} \\ \sigma^2 \qquad = p\boldsymbol{I} & \text{(b)} \end{array}\right\} (886)^{46}$$

26. Sequential analysis

Sequential analysis is one of the more recently developed statistical methods, and its use in medical trials is increasing[51]. It is illustrated here by two charts[52] that enable a comparison to be made, for example between two drugs, without calculation.

Example 75. The effect on patients of drug A is to be compared with that of drug B. Two patients are selected, the toss of a coin deciding which one is to receive drug A and which drug B. They should receive the drugs *simultaneously or in quick succession.* The result is given one of the three ratings

Drug A better Drug B better No difference

If drug A is better, a cross is made in the square immediately *above* the black square in the charts (Figs. 49 and 50). If drug B is better, a cross is made in the square immediately *to the right* of the b[lack] square. If there is no difference, no entry is made in the chart. [A] second test is then made in exactly the same way with two diffe[rent] patients and the result entered in the square above or to the rig[ht of] that marked in the first test, and so on for successive tests. As soo[n as] a barrier is overstepped one of the following decisions can be m[ade]:

(a) upper barrier overstepped: drug A is better
(b) lower barrier overstepped: drug B is better
(c) middle barrier overstepped: no difference demonstrate[d]

The significance probability for (a) and (b) combined is 2α.

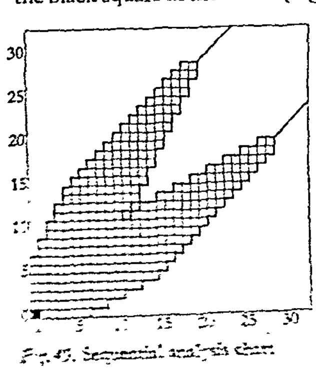


Fig. 49. Sequential analysis chart

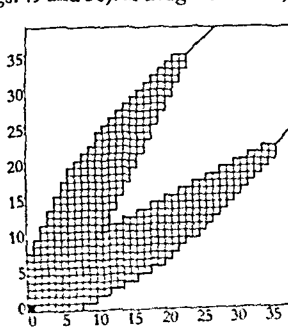


Fig. 50. Sequential analysis chart

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Symbols – Abbreviations

(Combinations and multiples of symbols like cm, m², km h⁻¹, etc are not included)

Symbol	Name	Page
	(sexagesimal) minute	207
	(sexagesimal) second	207
	degree	207
	square degree	207
	right angle	207
	are	203
	atto-(10^{-18})	9
	year (astronomy)	206
	atomic mass unit (old)	227
	apothecaries' (measures)	205
	apostilb	223
	technical atmosphere	212
	physical atmosphere	212
	avoirdupois (measures)	205
	ampere	215, 216
	astronomical unit	200
	ångstrom	200, 202
	barn	202, 203
	bar	211
	barrel	204
	bushel	203, 204
Btu	British thermal unit	213
	centesimal minute	207
	centi-(10^{-2})	9
	cycle per second	208
	15° calorie	213
	Int Steam Table calorie	213
[illegible]	thermochemical calorie	213
	centesimal second	207
	candela	223
	chain	200
	metric horsepower	213
	reciprocal centimetre	213
	hundredweight	205
	coulomb	216
	degree Celsius (Centigrade)	208
	curie	217
	deci-(10^{-1})	9
	day	205
	deca-(10^{1})	9
	decibel	225
	dram, drachm	205
	dry pint	204
	dry quart	204
	pennyweight	205
	dyne	211
	electromagnetic unit	215
	erg	212, 213
	electrostatic unit	215
	electron volt	213
	gramme-equivalent	226
	femto-(10^{-15})	9
	fathom	200
	fluid dram (fluid drachm)	204
	fluid ounce	204
	foot	200
	foot of water	212
	furlong	200
F	farad	216
°F	degree Fahrenheit	209
G		
ᵍ	grade	207
g	gramme	204, 213
gal	gallon	203
gf	gramme-force	211
gi	gill	204
gr	grain	204
grf	grain-force	211
G	giga-(10^{9})	9
Gal	galileo	210
Gb	gilbert	216
Gs	gauss	216
γ (μg)	gamma* (microgramme)	204
H		
h	hecto-(10^{2})	9
h	hour	205
hp	horsepower	214
H	henry	216
Hz	hertz (cycle per second)	208
I		
in	inch	200
inHg	inch of mercury	212
inH_2O	inch of water	212
J		
J	joule	212, 213, 216
K		
k	kilo-(10^{3})	9
kgf	kilogramme-force	211
kn	knot	200
K	kelvin	208, 213
L		
l	litre	203
lb	pound	204
lbf	pound-force	211
li	link	200
liq pt	liquid pint	204
liq qt	liquid quart	204
lm	lumen	222
lx	lux	223
l y	light year	201
L	lambert	223
M		
m	milli-(10^{-3})	9
m	metre	200
mi	mile	200
min	minute	205
min	minim	204
mmHg	millimetre of mercury	212
mmH_2O	millimetre of water	212
mol	mole	226
M	mega-(10^{6})	9
Mx	maxwell	216
μ	micro-(10^{-6})	9
μ (μm)	micron* (micrometre)	200
N		
n	nano-(10^{-9})	9
n mile	nautical mile	200
N	newton	211, 216
O		
osm	osmole	271
oz	ounce	205
Oe	oersted	216
Ω	ohm	215, 216
$Ω^{-1}$	mho (reciprocal ohm)	216
P		
p	pico-(10^{-12})	9
p	pond	211
pc	parsec	201
pdl	poundal	211
phon	phon	225
phot	phot	223
pk	peck	204
pt	pint	204
P	poise	214
PS	metric horsepower	214
Q		
qr	quarter	205
qt	quart	205
R		
r	revolution	208
r	roentgen (old)	218
rad	radian	207
rd	rad	218
rd	rod	200
rem	rem	221
R	roentgen	218
°R	degree Rankine	208
Ry	rydberg	213
S		
s	second	205
s	scruple	205
s^{-1}	reciprocal second	208, 213
sb	stilb	223
sh cwt	short hundredweight	205
sh tn	short ton	205
sone	sone	225
sr	steradian	207
st	stere	203
St	stokes	214
T		
t	metric ton	204
t, tr	troy (measures)	205
ton	ton	205
tonf	ton-force	211
T	tera-(10^{12})	9
T	tesla	216
torr	torr	212
U		
u	atomic mass unit	213, 226
V		
V	volt	215, 216
W		
W	watt	214, 216
Wb	weber	216
X		
XU	X-unit	201
Y		
yd	yard	200

* This name and symbol should no longer be used

centimetre gramme second (system of units)
Comité International des Poids et Mesures
International Astronomical Union
International Commission on Radiological Units and Measurements

IUPAC International Union of P
IUPAP
MKS
MKSA
RBE

Length (l)

Dimension $= \mathrm{L}$

Coherent units

International System of Units: metre (m)
CGS system: centimetre (cm)
ft-lb-s system: foot (ft)

International System of Units (SI units)[1]

The base (or 'basic') unit of length is the metre** (m). This was re-defined[1a] in 1960 as a multiple of the vacuum wave length λ (^{86}Kr) of the orange-red spectral line of the atom of krypton-86, as follows: The metre is the length equal to 1650763.73 wave lengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom. The re-defined metre is therefore based on a natural quantity, namely the energy difference between two electron terms of an unperturbed atom. It follows that

$$\lambda\,(^{86}\mathrm{Kr}) = 6.057\,802\,21 \times 10^{-7}\ \text{metre}$$

For the history of the metre as a unit see the literature[2].

Secondary standards[3]

(a) Vacuum wave lengths of the krypton nuclide ^{86}Kr

$2p_9 - 5d_4'$: $6.458\,072\,0 \times 10^{-7}$ m
$2p_8 - 5d_4$: $6.422\,800\,6 \times 10^{-7}$ m
$1s_3 - 3p_{10}$: $5.651\,128\,6 \times 10^{-7}$ m
$1s_4 - 3p_8$: $4.503\,616\,2 \times 10^{-7}$ m

(b) Vacuum wave lengths of the mercury nuclide ^{198}Hg

$6^1P_1 - 6^1D_2$: $5.792\,268\,3 \times 10^{-7}$ m
$6^1P_1 - 6^3D_2$: $5.771\,198\,3 \times 10^{-7}$ m
$6^3P_2 - 7^3S_1$: $5.462\,270\,5 \times 10^{-7}$ m
$6^3P_1 - 7^3S_1$: $4.359\,562\,4 \times 10^{-7}$ m

(c) Vacuum wave lengths of the cadmium nuclide ^{114}Cd

$5^1P_1 - 5^1D_2$: $6.440\,248\,0 \times 10^{-7}$ m
$5^3P_2 - 6^3S_1$: $5.087\,237\,9 \times 10^{-7}$ m
$5^3P_1 - 6^3S_1$: $4.801\,252\,1 \times 10^{-7}$ m
$5^3P_0 - 6^3S_1$: $4.679\,458\,1 \times 10^{-7}$ m

Conversion of metric units of length

A		1 **A** unit = b **B** units (b in the table) — **B**						
Name	Symbol	nm	µm	mm	cm	dm	m	km
ångström	Å	10^{-1}	10^{-4}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-13}
nanometre (millimicron†)	nm (mµ†)	1	10^{-3}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-12}
micrometre (micron†)	µm (µ†)	10^{3}	1	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-9}
millimetre	mm	10^{6}	10^{3}	1	10^{-1}	10^{-2}	10^{-3}	10^{-6}
centimetre	cm	10^{7}	10^{4}	10	1	10^{-1}	10^{-2}	10^{-5}
decimetre	dm	10^{8}	10^{5}	10^{2}	10	1	10^{-1}	10^{-4}
metre	m	10^{9}	10^{6}	10^{3}	10^{2}	10	1	10^{-3}
decametre	dam	10^{10}	10^{7}	10^{4}	10^{3}	10^{2}	10	10^{-2}
hectometre	hm	10^{11}	10^{8}	10^{5}	10^{4}	10^{3}	10^{2}	10^{-1}
kilometre	km	10^{12}	10^{9}	10^{6}	10^{5}	10^{4}	10^{3}	1

† In accordance with a resolution of the 13th General Conference of Weights and Measures (1967), these names and symbols, formerly in common use, should no longer be used.

Anglo-Saxon systems of measurement

The primary standard of length in the Anglo-Saxon systems of measurement is the *yard* (yd), though the coherent length unit in the ft-lb-s system is the foot (ft) = ⅓ yard. Recently the yard has been defined in terms of the metre as follows[4]:

$$1\ \text{yard} = 0.9144\ \text{m} = 1.509\,458\,3_5 \times 10^{6}\ \lambda\,(^{86}\mathrm{Kr})$$

This newly defined 'unified' yard† lies between the former imperial yard of the United Kingdom[5] and the former US yard[6]:

$$1\ \text{imperial yard} = 0.914\,398\,41\ \text{m} < 1\ \text{unified yard} < 1\ \text{US yard} = (36/39.37)\ \text{m} = 0.914\,401\,83\ \text{m}^{\dagger\dagger}$$

Conversion of Anglo-Saxon units of length

A		1 **A** unit = b **B** units (b in the table) — **B**		
Name	Symbol	yd	ft	m
mil	–	1/36 000	1/12 000	2.54×10^{-5}
point (printers') (US)†	–	–	–	3.515×10^{-4}
line (button) (US)	–	1/1440	1/480	6.35×10^{-4}
inch	in	1/36	1/12	2.54×10^{-2}
hand (US)	–	1/9	1/3	1.016×10^{-1}
link	li ††	22/100	66/100	$2.011\,68 \times 10^{-1}$
span (US)	–	1/4	3/4	2.286×10^{-1}
foot	ft	1/3	1	3.048×10^{-1}
yard	yd	1	3	9.144×10^{-1}
fathom	fath ††	2	6	1.8288
rod (pole, perch)	rd ††	11/2	33/2	5.0292
chain	ch ††	22	66	$2.011\,68 \times 10$
furlong	fur. ††	220	660	$2.011\,68 \times 10^{2}$
(statute) mile	mile †††	1760	5280	$1.609\,344 \times 10^{3}$

† Definition: 1 point (printers') (US) = 0.013 837 in.
†† Symbols in use only in USA.
††† Symbol in USA: mi.

Nautical and geodetic units of length

The *nautical mile* is defined as the length of the mean minute of arc on the meridian of the earth (mean minute of latitude). When the values of the terrestrial polar and equatorial radii derived from the international terrestrial geoid[7] are used

$$1\ \text{nautical mile} = \frac{\text{quadrant of meridian } Q_{\delta}^{\mathrm{Me}}}{90 \times 60} = 1852.276\ \text{m}$$

In 1928 the International Hydrographic Conference in Monaco proposed the following international unified definition[8]:

$$1\ \text{international nautical mile} = 1852\ \text{m}$$

This value was accepted by all maritime nations (by USA in 1954[9]) with the exception of the United Kingdom, where the nautical mile is based on the knot:

$$1\ \text{Admiralty knot} = \frac{1\ \text{nautical mile}}{\text{hour}} = 6080\ \text{imperial feet per hour}$$

whence

$$1\ \text{imperial nautical mile (n mile)} = 1853.181\ \text{m}$$

The *geographical mile* (not to be confused with the land, or statute, mile) is now based on the equatorial quadrant Q_{δ}^{E} (≙ 4 minutes of arc on the equator). When the value of the terrestrial equatorial radius derived from the international terrestrial geoid[7] is used

$$1\ \text{geographical mile} = 4 \times \frac{\text{equatorial quadrant } Q_{\delta}^{\mathrm{E}}}{90 \times 60} = 7421.591\ \text{metres}$$

Astronomical units of length

In astronomy the unit of length is the *astronomical unit* (AU). This is based on a definition requiring some preliminary explanation. With the ephemeris day (d) of 86 400 ephemeris seconds (s) as time unit and the mass of the sun ($M_\odot$) as mass unit the undisturbed elliptical ('Kepler') path of a planet is characterized by

- n the sideral mean daily motion (angular velocity) in rad/d
- $\bar{m}$ the mass in $M_\odot$
- a the semi-major axis in AU
- k the Gauss gravitational constant in $(\mathrm{AU})^{3/2}\ \mathrm{rad}\ \mathrm{d}^{-1}\ M_\odot^{-1/2}$

* This chapter (pages 200–227) has been compiled in collaboration with G. Becker, W. Fritz, J. Hoppe-Blank, W. Hübner, H. Stille, H.-M. Weiss, Braunschweig, and S. Böhme, Heidelberg.
** In the USA, 'meter'.

† Formerly also called 'international yard' in English-speaking countries.
†† In the US Coast and Geodetic Survey the foot legally defined in 1866 and 1893[6] (US Survey Foot = 12/39.37 m ≈ 0.304 800 609 m) retains its validity, for instance for the basic geodetic survey networks of the United States (see National Bureau of Standards[4]).

The AU is then defined as that unit in which the quantity a is measured in KEPLER's Third Law $n^2 a^3 = k^2 (1 + \bar{m})$ (as equation between numerical values) with the conventionally agreed numerical value $k = na^{3/2} = 0.017\,202\,098\,95$ for the GAUSS gravitational constant, measured in $(AU)^{3/2}$ rad $d^{-1} M_\odot^{-1/2}$. The AU is thus a derived unit determined by the units chosen for time and mass and the fixed value of the GAUSS constant k. It can be described as the

was the reason for GAUSS's measurement of k) When the disturbing effects of the other planets are taken into account the value is 1.000 000 2 AU.

It is still necessary to express the AU as a multiple A of the metre or some other reference length The former is obtained directly from radar measurements (up to now mainly of the planet Venus, whose distance is known from the ephemerides), determination of the solar parallax $\pi_\odot$ measures the relationship of the AU to the equatorial radius a_e of the earth The 'IAU System of Astronomical Constants' was laid down by the 12th General Assembly of the International Astronomical Union in 1964[10] by assigning conventionally agreed values to the 'defining' and 'primary' constants In this system

$$1\ \text{AU} = A\ \text{m} = 149\,600 \times 10^6\ \text{m}$$
$$\pi_\odot = \text{arc sin}\,(a_e/A\,m) = 8.794\,05'', \text{ with } a_e = 6\,378\,160\ m$$

Since radar measurements are measurements of time differences the time τ_A taken by light to travel 1 AU is also given, in the same system it is

$$\tau_A = (A\ \text{m})/c = 499.012\ \text{s, with } c = 299\,792.5 \times 10^3\ \text{m s}^{-1}\ ^{10,11}$$

In stellar astronomy the distances involved are far greater than those of the solar system ($> 2 \times 10^5$ AU), and more appropriate length units have been introduced, namely the parsec, light year and

parallax and second) Since $p < 0.8''$ for all stellar parallaxes, parallax and distance are related as follows

$$\pi r p/648\,000'' = 1\ \text{AU}$$
whence $r = 648\,000''/(\pi p)$ AU
and $r = 1/p$ pc by definition

It follows that $1\ \text{pc} = 648\,000/\pi\ \text{AU} = 206\,264.8\ \text{AU}$
and $1\ \text{pc} = 648\,000/\pi\ A\ \text{m} = 3.085\,72 \times 10^{13}\ \text{km}$

The larger units usually employed are

$$1\ \text{kpc} = 10^3\ \text{pc},\ 1\ \text{Mpc} = 10^6\ \text{pc}$$

The *light year* (l y) is the distance travelled by light in one tropical year When the values of the IAU System of Astronomical Constants[10] for the velocity of light and the number of ephemeris seconds in 1 tropical year are used

$$1\ \text{l y} = 299\,792\,500\ \text{m s}^{-1} \times 31\,556\,925.9747\ \text{s}$$
$$= 9.460\,529\,73 \times 10^{12}\ \text{km}$$

For objects whose parallax cannot be (more or less) directly measured, the *distance modulus* is used as indirect measure of distance

propagation of light in an absorption-free space

$$m - M = 5 \log_{10}(r/\text{pc}) - 5 = -5 - 5 \log_{10}(p/'')$$

For $m - M = -5^m, 0^m, +5^m, +10^m, \ldots +25^m$ the corresponding distances are $r = 1, 10, 100, 1000, \ldots 10^6$ pc

If M can be determined from the physical structure of the object, r or p can be obtained from

$$\log_{10}(r/\text{pc}) = 0.2\,(m - M + 5) = -\log_{10}(p/'')$$

Conversion of astronomical units of length†

A		1 A unit = b B units (b in the table)		
Name	Symbol	AU	pc	l y
astronomical unit	AU	1	$4.848\,14 \times 10^{-6}$	$1.581\,31 \times 10^{-5}$
parsec	pc	$2.062\,648 \times 10^5$	1	3.261 68
light year	l y	$6.323\,88 \times 10^4$	$3.065\,91 \times 10^{-1}$	1

† Based on the values of the solar parallax and terrestrial equatorial radius laid down by the International Astronomical Union in 1964[10].

Spectrometric units of length

X-Unit

$$1\ \text{XU} = [1/3029.45\ d_{\text{III}}^{18°}\ (\text{CaCO}_3)]$$

The very great accuracy necessary in X-ray wave-length measurements (relative uncertainty $\approx 10^{-6}$) is no longer met by SIEGBAHN's definition of the X-unit since the natural imperfections of the calcite crystal (impurities, lattice defects, mosaic- or superstructure, sur-

indirect methods of other workers In a later discussion of these

mean based on the values for constants resulting from the 1963 adjustment[19] (see page 228) Earlier, in 1965, a *special re-evaluation of the atomic constants* by COHEN and DUMOND[19] led to a value of $\Lambda = 1.002\,080\ (3\ s = 18 \times 10^{-6})$ based on $\lambda(\text{WK}\alpha_1) = 208.577\,0$ XU

In 1964 BEARDEN et al [21] published the results of very precise determinations

million smaller than the existing tabulated values[15,16], so that taking $\lambda(\text{MoK}\alpha_1) = 707.831$ XU

derived the following mean values for the conversion factor Λ (relative probable error $\pm 5 \times 10^{-6}$).

$$\Lambda = 1.002\,076 \text{ based on } \lambda(\text{MoK}\alpha_1) = 707.831 \text{ XU or } \lambda(\text{CuK}\alpha_1) = 1537.370 \text{ XU}$$
$$= 1.002\,056 \text{ based on } \lambda(\text{CuK}\alpha_1) = 1537.400 \text{ XU or } \lambda(\text{MoK}\alpha_1) = 707.845 \text{ XU}$$

At the same time BEARDEN[24] suggested that SIEGBAHN's definition of the XU should be replaced by a new scale of X-ray wave lengths whose unit should be denoted provisionally by Å and de-

* Some authorities[14] still use the value[13] 1 XU = (1.002 02 ± 0.000 03) mÅ agreed on in 1942 between SIEGBAHN, the X Ray Analysis Group of the Institute of Physics (UK) and the American Society for X-Ray and Electron Diffraction

fined by adopting an exact value of the wave length of the peak of the $WK\alpha_1$ line, namely $\lambda(WK\alpha_1) = 0.2090100$ Å. This defining value had been derived by BEARDEN in 1964 from the value of $\lambda(WK\alpha_1) = 208.5770$ XU $= 208.5770 \times \Lambda$ mÅ and his experimentally determined value $\Lambda = 1.002076$ based on the 'working standard' wave length $\lambda(MoK\alpha_1)$; this means that the new X-ray wave-length unit also satisfies the relationship 1 mÅ $= (1.002076 \pm 5 \times 10^{-6})^{-1}$ XU. According to BEARDEN, 1 Å is identical with 1 Å (within a relative probable error of $\pm 5 \times 10^{-6}$).

Subsequently BEARDEN, in conjunction with six collaborators, prepared a new table[25] of some 2700 wave lengths of X-ray fluorescence lines of the K-, L-, M-, N- and O-series (given as maximum of the line profile) and X-ray absorption edges in his proposed Å unit; this includes in an appendix a table of the wave lengths in XU based on $\lambda(WK\alpha_1) = 208.5770$ XU.

In 1967 BEARDEN's wave-length table was re-published[26] with the following changes: 1. The new X-ray wave-length unit defined by the value $\lambda(WK\alpha_1) = 0.2090100$ is given the symbol Å* [1 Å* $= (1 \pm 5 \times 10^{-6})$Å]. 2. As 'working standard' the wave length $\lambda(CuK\alpha_1) = 1537.400$ XU is given, with a resulting experimental Λ value of 1.002056. 3. The wave lengths are given in Å* only (the appendix with values in XU is omitted). 4. The wave lengths of the 4 secondary standard lines are given in Å* only: $\lambda(AgK\alpha_1) = 0.5594075$ Å*, $\lambda(MoK\alpha_1) = 0.709300$ Å*, $\lambda(CuK\alpha_1) = 1.540562$ Å*, $\lambda(CrK\alpha_2) = 2.393606$ Å* [relative probable error compared to the primary standard wave length $\lambda(WK\alpha_1) = 0.2090100$ Å*: $\pm 1.1 - 1.3 \times 10^{-6}$].

When using BEARDEN's tables it should be noted that in the original publication[25] the Λ value 1.002076 was based on a *MoKα₁ X-unit*, i.e., it was derived from the value $\lambda(MoK\alpha_1) = 707.831$ XU [or $\lambda(CuK\alpha_1) = 1537.3700$ XU or $\lambda(WK\alpha_1) = 208.5770$ XU], whereas in the later publication[26] the Λ value 1.002056 is based on a 20 parts per million smaller *CuKα₁ X-unit* derived from the value $\lambda(CuK\alpha_1) = 1537.400$ XU′ [or $\lambda(MoK\alpha_1) = 707.845$ XU′ or $\lambda(WK\alpha_1) = 208.5810$ XU′].

The relationship 1 Å* $= (1 \pm 5 \times 10^{-6})$ Å given by BEARDEN for his new X-ray wave-length unit will remain valid only as long as 1. the relevant 'working standard' wave length [$\lambda(MoK\alpha_1)$ for the original tables[25] and $\lambda(CuK\alpha_1)$ for the later publication[26]] and the wave-length ratios $\lambda(CuK\alpha_1)/\lambda(MoK\alpha_1) = 2.171945$ and $\lambda(CuK\alpha_1)/\lambda(WK\alpha_1) = 7.370757$ (relative probable errors $\pm 1.0 \times 10^{-6}$ and $\pm 1.1 \times 10^{-6}$) are adhered to, and 2. doubt is not thrown on the Λ value (1.002076 or 1.002056) based on the relevant 'working standard' wave length by new experimental results, whether these are direct or indirect determinations of Λ or new values for the atomic constants involved, in particular the AVOGADRO constant N_A. The second of these conditions could be avoided if, instead of introducing a new wave-length unit such as BEARDEN proposes, the now practically defunct SIEGBAHN definition of the X-unit were replaced by a new one based for instance on the $WK\alpha_1$ line: 1 XU $= \lambda(WK\alpha_1)/208.5770$ or $\lambda(WK\alpha_1)/208.5810$. Up to now the international bodies concerned have been unable to agree on a new definition of the X-unit.

Tables of the atomic energy differences (in eV and Ry; see page 213) between two levels together with the wave lengths (in mÅ*) corresponding to the energy differences are to be found in BEARDEN and BURR's tables of atomic energy levels[27]. Some examples of energy differences are also given in the tables of energy levels published by these authors in *Reviews of Modern Physics*[28].

The ångström

The ångström (Å) is widely used as a *unit of length in atomic and molecular spectrometry*, especially in the visible and ultraviolet spectral range. Following the new definition of the metre by the 11th General Conference on Weights and Measures[1] in 1960, the International Astronomical Union in 1961 replaced its 1907 definition[29] of the ångström based on the wave length of cadmium as primary standard by the relationship[30]

1 ångström $= 10^{-10}$ metre

Ångström is thus now no more than a special name for 10^{-10} m.

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Area (A or S)

Dimension $= L^2$

Coherent units

International System of Units: square metre (m²)
CGS system: square centimetre (cm²)
ft-lb-s system: square foot (ft²)

The units of length on which the units of area are based are described on page 200.

The International Union of Pure and Applied Physics (IUPAP), at its 10th General Assembly in 1960, recommended the name barn (b) for 10^{-24} cm², a quantity in common use in atomic and nuclear physics as unit of nuclear cross section[1].

Conversion of metric units of area

A		B: 1 A unit = b B units (b in the table)					
Name	Symbol	μm^2	mm^2	cm^2	dm^2	m^2	km^2
barn .	b	10^{-16}	10^{-22}	10^{-24}	10^{-26}	10^{-28}	10^{-34}
square micrometre . .	μm^2	1	10^{-6}	10^{-8}	10^{-10}	10^{-12}	10^{-18}
square millimetre . .	mm^2	10^6	1	10^{-2}	10^{-4}	10^{-6}	10^{-12}
square centimetre .	cm^2	10^8	10^2	1	10^{-2}	10^{-4}	10^{-10}
square decimetre . .	dm^2	10^{10}	10^4	10^2	1	10^{-2}	10^{-8}
square metre	m^2	10^{12}	10^6	10^4	10^2	1	10^{-6}
square decametre . (are)	dam^2 (a)	10^{14}	10^8	10^6	10^4	10^2	10^{-4}
square hectometre . (hectare)	hm^2 (ha)	10^{16}	10^{10}	10^8	10^6	10^4	10^{-2}
square kilometre . . .	km^2	10^{18}	10^{12}	10^{10}	10^8	10^6	1

Conversion of Anglo-Saxon units of area

A		B: 1 A unit = b B units (b in the table)		
Name	Symbol	yd^2	ft^2	m^2
circular mil*	–	[illegible]	[illegible]	[illegible]
square inch	in^2	[illegible]	[illegible]	[illegible]
circular inch	–	[illegible]	[illegible]	[illegible]
square link	li** ***	[illegible]	[illegible]	[illegible]
square foot	ft^2	[illegible]	[illegible]	[illegible]
square yard	yd^2	[illegible]	[illegible]	[illegible]
square rod***	rd** ***	[illegible]	[illegible]	[illegible]
square chain	ch** ***	484	4356	4 046 86 × 10^2
rood (UK)	–	1210	10 890	1 011 71 × 10^3
acre	–	4840	43 560	4 046 86 × 10^3
square mile	mile^2 †	3 097 600	27 878 400	2 589 99 × 10^6

* The circular mil is defined as the area of a circle of 0 001 inch diameter 1 circular mil = 10^{-6} circular inch = $(\pi/4) \times 10^{-6}$ in^2

** Symbols in use onyl in USA

*** Also known as square perch or square pole

† Symbol in USA mi^2

Reference

[illegible]

Volume (V)

Dimension = L^3

Coherent units

International System of Units cubic metre (m^3)
CGS system cubic centimetre (cm^3)
ft-lb-s system cubic foot (ft^3)

The units of length on which the units of volume are based are described on page 200

Conversion of metric units of volume

A		B: 1 A unit = b B units (b in the table)					
Name	Symbol	nm^3	μm^3	mm^3	cm^3	dm^3	m^3
cubic nanometre	nm^3	1	10^{-9}	10^{-18}	10^{-21}	10^{-24}	10^{-27}
cubic micrometre	μm^3	10^9	1	10^{-9}	10^{-12}	10^{-15}	10^{-18}
cubic millimetre	mm^3	10^{18}	10^9	1	10^{-3}	10^{-6}	10^{-9}
cubic centimetre	cm^3	10^{21}	10^{12}	10^3	1	10^{-3}	10^{-6}
cubic decimetre	dm^3	10^{24}	10^{15}	10^6	10^3	1	10^{-3}
cubic metre (stere*)	m^3 (st)	10^{27}	10^{18}	10^9	10^6	10^3	1
cubic kilometre	km^3	10^{36}	10^{27}	10^{18}	10^{15}	10^{12}	10^9

* Name mainly in use in French-speaking countries.

Noncoherent unit

Up to 1964 the *litre* (l) was defined as the volume of 1 kg of pure air-free water at its maximum density (≈3 98 °C) under norma[l] atmospheric pressure (1 atm = 760 torr)[1]. In 1950 the Internationa[l] Committee of Weights and Measures[2] gave 1 litre = 1.00002[8] cubic decimetre (relative uncertainty ≈ ± 3 × 10^{-6}) as the bes[t] conversion factor between the litre so defined and the cubic deci metre.

In 1964 the 12th General Conference of Weights and Measures [illegible] tiples · 1 l = 1 dm^3

Conversion of decimal submultiples and multiples of the litre

A		B: 1 A unit = b B units (b in the table)			
Name	Symbol	µl	ml	l	m^3
microlitre (= 1 mm^3)	µl	1	10^{-3}	10^{-6}	10^{-9}
millilitre (= 1 cm^3)	ml	10^3	1	10^{-3}	10^{-6}
decilitre (= 0 1 dm^3)	dl	10^5	10^2	10^{-1}	10^{-4}
litre (= 1 dm^3)	l	10^6	10^3	1	10^{-3}
hectolitre (= 0 1 m^3)	hl	10^8	10^5	10^2	10^{-1}

Anglo-Saxon units of volume[4]

In the United Kingdom the *commercial* units of volume both fo[r] fluids and dry substances are the gallon (gal) and units derived fro[m] it The gallon is the volume of a quantity of water of a specifie[d] mass when weighed under the conditions laid down[5], this defin[i]tion results in the following relationships

1 gal(UK) = 277 42 in^3
= 4 546 09 dm^3

In the United States the gallon (gal) and the units of volum[e] derived from it are legal measures only for fluids The gallon [is] there defined[6, 7] as

1 *gal(US)* = 231 in^3
= 3.785 411 784 dm^3

whence the relationships

1 gal(US) = 0 832 674 gal(UK)
1 gal(UK) = 1 200 950 gal(US)

In the United States the units of volume for dry substances a[re] the bushel (bu) and units derived from it The bushel (bu) is define[d] as follows.

1 bu(US) = 2150 42 in^3
= 35 239 070 166 88 dm^3

This unit is related to the bushel used in the United Kingdo[m] defined as 1 bushel (UK) = 8 *gal(UK), as follows:*

1 bu(US) = 0 968 939 bushel(UK)
1 bushel(UK) = 1 032 057 bu(US)

Conversion of Anglo-Saxon units of volume

A		B: 1 A unit = b B units (b in the table)		
Name	Symbol	yd^3	ft^3	m^3
cubic inch	in^3	1/46 656	1/1728	1 638 706 4 × 10–
board foot (timber)	fbm	1/324	1/12	2 359 74 × 10^{-3}
cubic foot .	ft^3	1/27	1	2 831 68 × 10^{-2}
cubic yard	yd^3	1	27	7 645 55 × 10^{-1}
cord (timber) .	cd	128/27	128	3 624 56

Conversion of United Kingdom units of volume (UK units)

		1 **A** unit = b **B** units (b in the table)		
A		**B**		
Name	Symbol	gal	in³	l = dm³
minim	min	1/76 800	$3.612\,23 \times 10^{-3}$	$5.919\,39 \times 10^{-5}$
fluid drachm. (≈ 60 min)	fl dr	1/1280	$2.167\,34 \times 10^{-1}$	$3.551\,63 \times 10^{-3}$
fluid ounce .. (≈ 480 min)	fl oz	1/160	1.733 87	$2.841\,31 \times 10^{-2}$
gill	–	1/32	8.669 36	$1.420\,65 \times 10^{-1}$
pint	–	1/8	$3.467\,74 \times 10$	$5.682\,61 \times 10^{-1}$
quart	–	1/4	$6.935\,49 \times 10$	1.136 52
gallon	gal	1	$2.774\,20 \times 10^{2}$	4.546 09
peck	–	2	$5.548\,39 \times 10^{2}$	9.092 18
bushel	–	8	$2.219\,35 \times 10^{3}$	$3.636\,87 \times 10$
quarter ..... (volume)	–	64	$1.775\,49 \times 10^{4}$	$2.909\,50 \times 10^{2}$
chaldron	–	288	$7.989\,68 \times 10^{4}$	$1.309\,27 \times 10^{3}$

Conversion of United States units of volume (US units)

For fluids (liquid measure)

		1 **A** unit = b **B** units (b in the table)		
A		**B**		
Name	Symbol	gal	in³	l = dm³
minim	min	1/61 440	$3.759\,77 \times 10^{-3}$	$6.161\,15 \times 10^{-5}$
fluid dram ..	fl dr	1/1024	$2.255\,86 \times 10^{-1}$	$3.696\,69 \times 10^{-3}$
fluid ounce ..	fl oz	1/128	1.804 69	$2.957\,35 \times 10^{-2}$
gill	gi	1/32	7.218 75	$1.182\,94 \times 10^{-1}$
liquid pint ..	liq pt	1/8	$2.887\,5 \times 10$	$4.731\,76 \times 10^{-1}$
liquid quart .	liq qt	1/4	5.775×10	$9.463\,53 \times 10^{-1}$
gallon	gal	1	2.31×10^{2}	3.785 41
barrel (petroleum)[7,8]		42	9.702×10^{3}	$1.589\,87 \times 10^{2}$

For dry substances (dry measure)

		1 **A** unit = b **B** units (b in the table)		
A		**B**		
Name	Symbol	bu	in³	l = dm³
dry pint	dry pt	1/64	$3.360\,03 \times 10$	$5.506\,10 \times 10^{-1}$
dry quart ...	dry qt	1/32	$6.720\,06 \times 10$	1.101 22
peck	pk	1/4	$5.376\,05 \times 10^{2}$	8.809 77
bushel*	bu	1	$2.150\,42 \times 10^{3}$	$3.523\,91 \times 10$
barrel**	bbl	105/32†	7.056×10^{3}	$1.156\,27 \times 10^{2}$

* So-called stricken or struck bushel. There is also a heaped bushel of 2747.715 in³ ≈ 45.027 l for apples and a heaped bushel = 1¼ stricken bushels = 44.049 l[6,7].
** For fruit and other products except cranberries this barrel = 7056 in³; for cranberries the barrel = 5826 in³ ≈ 95.471 l[6,7].
† This fraction is approximate. Precise calculation based on the cubic inch definitions of bushel and barrel gives 1 bbl = (7056/2150.42) bu.

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Mass (m)

Dimension = M

Coherent units

International System of Units: kilogramme (kg)
CGS system: gramme (g)
ft-lb-s system: pound (lb)

International System of Units

The base unit of mass is the kilogramme (kg)*. It is equal to the mass of the international prototype of the kilogramme, a platinum-iridium cylinder preserved at the International Bureau of Weights and Measures in Sèvres (France)[1].

Conversion of metric units of mass

		1 **A** unit = b **B** units (b in the table)							
A		**B**							
Name	Symbol	ag	fg	pg	ng	µg	mg	g	kg
attogramme ..	ag	1	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}
femtogramme	fg	10^{3}	1	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}
picogramme ..	pg	10^{6}	10^{3}	1	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}
nanogramme .	ng	10^{9}	10^{6}	10^{3}	1	10^{-3}	10^{-6}	10^{-9}	10^{-12}
microgramme*	µg	10^{12}	10^{9}	10^{6}	10^{3}	1	10^{-3}	10^{-6}	10^{-9}
milligramme .	mg	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	1	10^{-3}	10^{-6}
gramme	g	10^{18}	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	1	10^{-3}
kilogramme ..	kg	10^{21}	10^{18}	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	1
metric ton (tonne)	t	10^{24}	10^{21}	10^{18}	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}

* Formerly also known as the gamma (γ), a name that should no longer be used.

Technical unit of mass

In the so-called 'technical system of measurement', the still widely used metre-kilopond-second system (m-kp-s system; on the kilopond see under 'Force', page 211) the coherent derived unit of mass, the so-called 'technical mass unit', is $1\ \mathrm{m^{-1}\ kp\ s^2} = 9.806\,65$ kg. This unit has been little used and with the rapidly increasing popularity of the SI units it will cease to have any importance. In technology the physical quantity mass (m) is usually replaced by the quotient weight/acceleration due to gravity (G/g) (see under 'Force', page 211), the unit of which is $1\ \mathrm{kp}/9.806\,65\ \mathrm{m\,s^{-2}}$, equal to the kilogramme of the MKS system.

International unit for precious stones

1 metric carat = 0.000 2 kg = 0.2 g = 200 mg[2]

Anglo-Saxon units of mass

In the Anglo-Saxon countries, in addition to the metric units employed in scientific work, three groups of mass units are in simultaneous use: the *avoirdupois* units of commerce and industry, the *troy* units for precious metals and coins, and the *apothecaries'* units. Common to all three groups is the grain (gr), defined as the 7000th part of the avoirdupois pound (lb avdp or lb av).

The avoirdupois pound has for some years been related[3] to the kilogramme by a precise numerical factor:

1 pound (lb) = 0.453 592 37 kg

* In the USA, usually 'kilogram'.

Name	Symbol	gr	lb	kg
grain (UK, US) .	gr	1	1/7000	6 479 891 $\times 10^{-5}$
dram (UK, US) ...	dr	875/32	1/256	1 771 85 $\times 10^{-3}$
ounce (UK, US)	oz	875/2	1/16	2 834 95 $\times 10^{-2}$
pound (UK, US)	lb	7 $\times 10^3$	1	4 535 923 7 $\times 10^{-1}$
stone (UK)	–	9 8 $\times 10^4$	14	6 350 29
quarter (UK)	qr	1 96 $\times 10^5$	28	1 270 06 $\times 10$
cental (UK)	–	7 $\times 10^5$	100	4 535 92 $\times 10$
short hundredweight (US) ..	sh cwt			
hundredweight (UK) ..	cwt	7 84 $\times 10^5$	112	5 080 23 $\times 10$
long hundredweight (US) . .	–			
(short) ton (US)	sh tn	1 4 $\times 10^7$	2000	9 071 85 $\times 10^2$
ton (UK)	ton	1 568 $\times 10^7$	2240	1 016 05 $\times 10^3$
long ton (US)	–			

Troy units

A		B (1 **A** unit = *b* **B** units, *b* in the table)		
Name	Symbol	gr	lb	g
pennyweight	dwt	24	3/875	1 555 17
troy ounce	oz tr*	480	12/175	3 110 35 $\times 10$
troy pound (US)	lb t	5760	144/175	3 732 42 $\times 10^2$

* In the United States oz t

Apothecaries' units

A		B (1 **A** unit = *b* **B** units, *b* in the table)		
Name	Symbol	gr	lb	g
scruple (UK) / apothecaries' scruple (US)	s apoth*	20	1/350	1 295 98
drachm (UK) / apothecaries' dram (US)	dr apoth*	60	3/350	3 887 93
apothecaries' ounce (UK, US)	oz apoth*	480	12/175	3 110 35 $\times 10$
apothecaries' pound (US)	lb apoth*	5760	144/175	3 732 42 $\times 10^2$

* In the United States, ap instead of apoth

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Time (t)

Dimension = T

Base unit, second (s)
(in all systems of measurement)

Time scales can be derived from all periodic natural phenomena (axial rotation of the earth, revolution of the planets and moon, transitions in atoms and molecules). The second of the International System of Units (SI units) is now (since October 1967) linked to an atomic frequency. it is defined as the duration of [illegible]

scale derived from the axial rotation of the earth is used For historical data on the second and on the 'atomic clock' see the literature[2]

Units of time derived from the earth's rotation · Universal Time

The *apparent solar day* is the time elapsing between two successive [illegible]

ment of a 'mean sun' assumed to move with uniform speed along the celestial equator in such a way that its passage through the vernal equinox (one of the intersections of the celestial equator and the ecliptic) coincides with that of the true sun The difference between apparent and mean solar time, known as the equation of time, varies in the course of the year between about +15 and −16 minutes. The mean solar day is the time elapsing between two successive passages of the mean sun through the meridian of the observer These passages define the time 12 noon of mean solar time (mean local time).

The mean solar day (d) is divided into 24 hours (h) each of 60 [illegible]

time elapsing between two successive passages of the vernal equinox through the meridian of the observer Since the position of the vernal equinox varies as a result of the *general precession* of the earth the stellar day is about 9 ms shorter than the time taken by the earth to complete a 360° revolution with respect to the fixed stars

d and d* are related by

$$d = d^*(1 + 1/n)$$

where n is the number of mean solar days in the tropical year.

The stellar day (d*) is divided into 24 stellar hours (h*) each of 60 stellar minutes (min*) each of 60 stellar seconds (s*)

On the *Universal Time* scale the time 12 noon UT is defined by the passages of the mean sun through the zero meridian (Greenwich). Statutory local time scales in use in particular countries are *zonal time* scales (15° difference of longitude ≈ 1 h), for example Central European Time (CET) = Universal Time + 1 h. For the differences between the various local times see the yearbooks issued by the Bureau des Longitudes[3].

Times on a particular time scale are often given with the symbols h, m (instead of min) and s raised, for example $2^h25^m3^s$ CET. In astronomy a particular point in time is known as an epoch.

Variations in the polar altitude of the earth and the seasonal variations in the earth's rotation (the latter in a pattern remaining roughly constant from year to year) result in changes in the length of the mean solar day that can be calculated. This has made it possible to define a more uniform scale of Universal Time known as UT 2. Up to 1956 the second of UT 2 was in use for very precise time measurements, but this practice has since been abandoned because the gradual slowing of the earth's rotational speed causes the second of UT 2 to increase by about 2×10^{-10} s per year. Moreover, irregular variations in the earth's rotation may result in fairly rapid changes in the UT second of, for instance, 10^{-8} s during the course of the year.

Multiples of the mean solar day and UT second

Calendar ordinary year = 365 mean solar days = 31536000 UT seconds

Calendar leap year = 366 mean solar days = 31622400 UT seconds

Mean Julian year (a_{jul}) = (3 calendar ordinary years + 1 calendar leap year)/4 = 365.25 mean solar days = 31557600 UT seconds

Mean Gregorian year (a_{greg}) = (400 a_{jul} − 3 d)/ 400 = 365.2425 mean solar days = 31556952 UT seconds

The definitions of the mean Julian and Gregorian years are chosen in such a way that their lengths approximate to that of the tropical year (ca. 365.2422 mean solar days). This figure is not constant but varies not only as a result of changes in the earth's rotation but also because the length of the tropical year itself is variable.

The zero point of the Universal Time scale is January 1 of the year 1 B.C. at 0^h UT, so that the number of the year indicates the number of complete calendar years that have since elapsed. It should be noted that only one calendar year separates 1 B.C. 0^h UT and 1 A.D. 0^h UT.

Up to 1581 each year exactly divisible by 4 was a leap year, as were the years 1, 5, 9, etc. B.C. This constituted the so-called Julian Calendar, introduced by Julius Caesar in 45 B.C. Owing to the fact that the Julian year is some 11 minutes longer than the tropical year (based on the earth's orbital motion) the Julian Calendar showed earlier and earlier dates for natural events like the seasons. The growing discrepancy was finally rectified by the calendar reform introduced by Pope Gregory XIII's bull of February 24 1582. Under this reform, 10 days were to be dropped from the calendar of the year 1582, October 5–14 inclusive, in order to restore the vernal equinox to March 21. France adopted the reform the same year, dropping the days from December 10 to 19 1582. In England the Gregorian Calendar was not adopted until 1752, when 11 days September 3–13, had to be dropped. In order to keep the Gregorian Calendar in step with the tropical years, the reform also laid down that three out of every four century years were to be ordinary years instead of leap years, i.e., that only those century years divisible by 400 were to be leap years. The mean Gregorian year is therefore 0.4 min longer than the tropical year.

Units of time derived from the orbital movement of the earth · Ephemeris Time

The following time intervals are derived from the revolution of the earth around the sun:

The *sidereal year* (a_{sid}) is the time taken by the earth to complete one 360° revolution around the sun, as related to the system of fixed stars. Since it cannot be measured directly the sidereal year is not used in time measurements.

The *anomalistic year* (a_{anom}) is the time elapsing between two successive passages of the earth through the perihelion.

The *astronomical year* (a_{astr}), also known as Bessel's year or annus fictus, is the time during which the right ascension of the (fictitious) mean sun increases by 360°; it differs only slightly from the tropical year.

The *tropical year* (a_{trop}), of great importance in time measurements, is the time elapsing between two successive passages of the true sun through the mean vernal equinox. Owing to the general precession of the earth the vernal equinox moves once round the ecliptic in about 26000 years. In addition to this movement, the vernal equinox is subject to a slight 'secular' acceleration as well as to periodic fluctuations. The fictitious *mean* vernal equinox is not subject to these periodic fluctuations. As a result of the general precession of the earth the tropical year is 20.4 min shorter than the sidereal year, and because of the secular acceleration of the vernal equinox each tropical year is about 5.3 ms shorter than the preceding one. The tropical year remains in phase with the seasons of the earth.

In order to construct calendars the approximate tropical year up to 1581 was calculated from the mean Julian year based on the mean solar day (a_{trop} is 11.2 min shorter) and for 1583 and subsequently from the mean Gregorian year likewise based on the mean solar day (a_{trop} is 0.4 min shorter). The tropical year is also 20.4 min shorter than the sidereal year and 25.1 min shorter than the anomalistic year.

The tropical year at a particular epoch is equal to $360°/(dL/dt)$, where L is the mean longitude of the sun, or angle subtended at the earth by the positions of the mean sun and the mean vernal equinox at that epoch. Owing to the secular acceleration of the vernal equinox the angular velocity dL/dt is a function of time. Of special importance is the length of the tropical year at the epoch 1900, January 0, 12 noon Ephemeris Time, which is December 31

Conversion of units of time

	A (Universal Time)		1 A unit = b B units (b in the table) — B (Universal Time)				
	Name	Symbol	s	min	h	d	Symbol
	second	s	1	$1.\dot{6} \times 10^{-2}$	$2.\dot{7} \times 10^{-4}$	$1.157\dot{4}\dot{0} \times 10^{-5}$	s
Mean solar time	minute	min	6×10	1	$1.\dot{6} \times 10^{-2}$	$6.9\dot{4} \times 10^{-4}$	min
	hour	h	3.6×10^3	6×10	1	$4.1\dot{6} \times 10^{-2}$	h
	day	d	8.64×10^4	1.44×10^3	2.4×10	1	d
	month 28 days		2.4192×10^6	4.032×10^4	6.72×10^2	2.8×10	month 28 d
	month 29 days		2.5056×10^6	4.176×10^4	6.96×10^2	2.9×10	month 29 d
	month 30 days		2.592×10^6	4.32×10^4	7.2×10^2	3×10	month 30 d
	month 31 days		2.6784×10^6	4.464×10^4	7.44×10^2	3.1×10	month 31 d
	year 365 days	a_{365}	3.1536×10^7	5.256×10^5	8.76×10^3	3.65×10^2	a_{365}
	year 366 days	a_{366}	3.16224×10^7	5.2704×10^5	8.784×10^3	3.66×10^2	a_{366}
Stellar time	stellar second[θ]	s*	9.972696×10^{-1}	1.662116×10^{-2}	2.770193×10^{-4}	1.154247×10^{-5}	s*
	stellar minute[θ]	min*	5.983617×10	9.972696×10^{-1}	1.662116×10^{-2}	6.925483×10^{-4}	min*
	stellar hour[θ]	h*	3.590170×10^3	5.983617×10	9.972696×10^{-1}	4.155290×10^{-2}	h*
	stellar day[θ]	d*	8.616409×10^4	1.436068×10^3	2.393447×10	9.972696×10^{-1}	d*
Calendar years	julian year	a_{jul}	3.15576×10^7	5.2596×10^5	8.766×10^3	3.6525×10^2	a_{jul}
	gregorian year	a_{greg}	3.1556952×10^7	5.259492×10^5	8.76582×10^3	3.652425×10^2	a_{greg}
	A (Ephemeris Time)		B (Ephemeris Time)				
At time 1900.0	sidereal year[θ]	a_{sid}	3.15581497×10^7	5.25969162×10^5	8.76615271×10^3	3.65256363×10^2	a_{sid}
	tropical year[θ]	a_{trop}	3.15569260×10^7	5.25948766×10^5	8.76581277×10^3	3.65242199×10^2	a_{trop}
	anomalistic year[θ]	a_{anom}	3.15584330×10^7	5.25973883×10^5	8.76623138×10^3	3.65259641×10^2	a_{anom}

899, 12 noon plus ca 4 5^{s} Universal Time At this time the mean

moon's orbital and the earth's axial rotational frequencies is well known

mean solar day (i e , seconds of Universal Time) at the time 1900 0 This is, however, incorrect The mean day is NEWCOMB's calculated mean value of the mean solar day during the period 1680–1895

Units of time derived from atomic transitions - Atomic Time

Atomic Time is based on the frequencies corresponding to hyperfine structure transitions in the atoms of the caesium, hydrogen and thallium nuclides ^{133}Cs, ^{1}H and ^{205}Tl, in the classical interpretation such transitions are due to the precession of the electrons of the o

riods of the atomic frequencies must be counted continuously A typical instrument for this purpose is variously known as a caesium beam apparatus, caesium atomic clock or caesium time and frequency standard.

Since the ephemeris second is known only to an accuracy of 10^{-9} s and is thus inadequate for precise time and frequency measurements the

hyperfine structure transition of the ^{133}Cs atom The 13th General Conference of Weights and Measures[1] in October 1967 adopted this relationship as the basis for the *new definition* of the SI second, and the ephemeris second continues to be used only in astronomy

Standard frequency and time-signal transmitters transmit time signals by various systems Thus UTC (Coordinated Universal Time) signals are transmitted partly with the aid of a time scale derived from atomic clocks that agrees approximately with Universal Time 2 and remains unchanged in each case for one calendar year When the deviation from Universal Time exceeds 0 1 s the UTC signals are adjusted Other transmitters send out SAT (Stepped Atomic Time) signals whose time unit is the atomic second Here too the time signals are adjusted only when the deviation from Universal Time exceeds 0 1 s.

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8 Values from or calculated from Bureau des Longitudes, *Annuaire 1966*, Gauthier-Villars, Paris, 1965

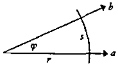
Angle ($\alpha, \beta, \gamma, \vartheta, \varphi$)

Dimension = L^{0}

Plane angles

SI unit radian (rad) = 1 m/m

The plane angle φ between two straight lines a and b is as the ratio of the arc s to the radius r of a circle whose ce at the point of intersection of the lines



$$\varphi = \frac{s}{r}$$

Since the angle φ is the ratio of two lengths it is a dimen quantity

the degree

1 degree (°) = 60 minutes (′) = 60 × 60 seconds (″)

The grade is subdivided centesimally

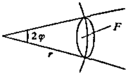
1 grade (^{g}) = 100 centesimal minutes (^{c}) = 100 × 100 cen seconds (^{cc})

The radian, right angle and whole circular angle are sub decimally without special designation

Solid angles (Ω)

SI unit steradian (sr) = 1 m^{2}/m^{2}

The solid angle Ω is defined as the ratio F/r^2, where F is t of the surface of a sphere of radius r cut out by a cone who coincides with the centre of the sphere



$$\Omega = \frac{F}{r^2}$$

Since the solid angle is the ratio of two areas it is lik dimensionless quantity. When the apical angle of the con the following relation holds

$\Omega = 2\pi(1 - \cos\varphi)$

The steradian (sr) is defined as the solid angle subtende centre of a sphere of unit radius by a cap of unit area on the of the sphere The *square degree* [symbol: □° or (°)^{2}] is def $(\pi/180)^2$ sr, the *square grade* [symbol (^{g})^{2}] by $(\pi/200)^2$ sr

Conversion of plane angles

		1 **A** unit = *b* **B** units (*b* in the table)		
A		**B**		
Name	Symbol	°	g	rad
degree	°	1	$1.\dot{1}$	$1.745\,328 \times 10^{-2}$
minute	′	$1.\dot{6} \times 10^{-2}$	$1.851\,85 \times 10^{-2}$	$2.908\,882 \times 10^{-4}$
second	″	$2.\dot{7} \times 10^{-4}$	$3.086\,420 \times 10^{-4}$	$4.848\,137 \times 10^{-6}$
grade	g	9×10^{-1}	1	$1.570\,796 \times 10^{-2}$
centesimal minute	c	9×10^{-3}	10^{-2}	$1.570\,796 \times 10^{-4}$
centesimal second	cc	9×10^{-5}	10^{-4}	$1.570\,796 \times 10^{-6}$
radian	rad	$5.729\,579 \times 10$	$6.366\,198 \times 10$	1
right angle	∟	9×10	10^2	1.570 796
whole	2 π rad	3.6×10^2	4×10^2	6.283 185

Conversion of solid angles

		1 **A** unit = *b* **B** units (*b* in the table)		
A		**B**		
Name	Symbol	□°	$(^g)^2$	sr
square degree	□° $(^\circ)^2$	1	1.234 568	$3.046\,174 \times 10^{-4}$
square grade	$(^g)^2$	8.1×10^{-1}	1	$2.467\,401 \times 10^{-4}$
steradian	sr	$3.282\,806 \times 10^3$	$4.052\,847 \times 10^3$	1

Frequency (ν or $f = 1/T$; T = period)

Dimension = T^{-1}

SI unit: hertz (Hz) = 1 s^{-1}

In Anglo-Saxon usage the reciprocal second as frequency unit is sometimes designated cycle per second (c/s), often wrongly shortened to cycle (c). 1 kilohertz (kHz; kilocycle per second, kc/s) = 1000 Hz.

Angular frequency (pulsatance) $\omega = 2\pi f$ should not be expressed in hertz (Hz) but in reciprocal seconds (s^{-1}). 1 reciprocal millisecond (ms^{-1}) = 1000 s^{-1}.

Frequency of rotation (n)

Dimension = T^{-1}

SI unit: reciprocal second (s^{-1})

Other units

Revolution/second (r s^{-1}) = 1 s^{-1}; revolution/minute (r min^{-1}) = $1.\dot{6} \times 10^{-2}$ s^{-1}; revolution/hour (r h^{-1}) = $2.\dot{7} \times 10^{-4}$ s^{-1}; revolution/day (r d^{-1}) = $1.57\dot{4}\dot{0} \times 10^{-5}$ s^{-1}

Temperature

Dimension = Θ

The concepts *temperature* and *heat* (quantity of heat) are rigorously differentiated in physics. The same quantity of heat can be distributed over a larger or smaller amount of the same material, which will have a lower temperature in the former case than in the latter.

Heat is a form of energy (see 'Energy', page 212), while the temperature of a body is a measure of the average kinetic energy per degree of freedom of the constituent molecules. Since it is related to the average movement of the latter, the concept of temperature can be applied only to bodies consisting of a large number of molecules. This simple relationship no longer applies at very low temperatures.

Thermodynamic temperature (T) and temperature scales

The only term for temperature that allows clear and consistent expression of all the states, processes and laws of thermodynamics is the thermodynamic temperature T, whether this is introduced by way of relationships between quantities of classical thermodynamics (for instance, the amounts of heat and work in a Carnot cycle or the behaviour of ideal gases) or statistically defined (either kinetically, starting from the energy distribution of the molecules of a system or from the characteristic parameter $\Theta = kT$ of the Gibbs canonical distribution in statistical mechanics)[1]. In a Carnot cycle operating between two temperatures T_1 and $T_2 < T_1$ the amounts of heat Q_1 and Q_2 absorbed or liberated are proportional to the corresponding temperatures: $Q_1/Q_2 = T_1/T_2$. According to the Second Law of Thermodynamics the thermodynamic temperature T has a lowest value below which it cannot fall and which can be given the value zero: the 'absolute zero' of thermodynamics. In a Carnot cycle operating between a finite temperature T_1 and the absolute zero (a special case in physics) the efficiency (η = work done, ΔA, divided by the amount of heat removed, ΔQ) attains the value 1.

International System of Units

The base unit of thermodynamic temperature is the kelvin (K), defined[2,3] as the fraction **1/273.16** of the thermodynamic temperature T_{tr} of the triple point of water (the point at which the solid, liquid and gaseous phases of pure water are in equilibrium). The same name kelvin (K) is also used to express an interval or a difference of thermodynamic temperature $\Delta T = T_1 - T_2$*.

This definition is also the basis of the thermodynamic Kelvin scale, starting at the absolute zero T = **0** K, introduced by Lord Kelvin in 1848; as a linear scale this can be constructed from any variable quantity bearing a linear relationship to the thermodynamic temperature T. Such a simple relationship relates the energy of ideal gases to a function of temperature expressed by the equation of state $T = pV_{m0}/R$ (where p = gas pressure, V_{m0} = molar volume of an ideal gas, R = molar gas constant (see under 'Physical Constants', page 228) and can be determined experimentally by means of a gas thermometer.

Anglo-Saxon unit of thermodynamic temperature

Also occasionally used as unit of thermodynamic temperature is the degree Rankine (°R), defined as **5/9** of the kelvin[4]. The thermodynamic Rankine scale starts at the absolute zero T = **0** °R, and can likewise be realized by gas thermometry.

When expressing temperature interval $\Delta T = T_1 - T_2$ the degree Rankine is usually written degR.

Celsius temperature (t) and temperature scale

The Celsius temperature t assigned to a system is defined as the difference between the corresponding thermodynamic temperature T of the system and a special thermodynamic temperature $T_{0,C}$ the value of which has no special physical significance but is arbitrarily chosen and conventionally fixed[4,5,*]: $t = T - T_{0,C}$. The zero point defining Celsius temperature is the temperature $T_{0,C}$ = **273.15** K lying **0.01** K below the triple point of water.

To express Celsius temperatures the base SI unit kelvin is designated simply degree Celsius (°C). The thermodynamic Celsius scale is subdivided into the same intervals as the thermodynamic Kelvin scale but has a zero point displaced by **273.15** K. The Celsius temperature t_0 = **0** °C expresses the same temperature as the thermodynamic temperature $T_{0,C}$ = **273.15** K. The degree Celsius (°C) or the kelvin (K), as names and symbols for the same unit, may be used to express an interval or a difference of Celsius temperature $\Delta t = t_1 - t_2$ equal to an interval or difference of thermodynamic temperature $\Delta T = T_1 - T_2$.

Fahrenheit temperature (ϑ) and temperature scale

In English-speaking countries Fahrenheit temperature ϑ also continues in use for the time being. The Fahrenheit temperature assigned to a system is defined as the difference between the corresponding thermodynamic temperature T of the system and a special temperature $T_{0,F}$ established by convention and without special physical significance[4]: $\vartheta = T - T_{0,F}$. The zero point defining Fahrenheit temperature is the temperature $T_{0,F}$ = 459.67 °R lying 32.018 °R below the triple point of water.

To express Fahrenheit temperatures the degree Rankine is designated simply degree Fahrenheit (°F). The thermodynamic Fahrenheit scale is subdivided into the same intervals as the thermodynamic Rankine scale but has a zero point displaced by 459.67 degR. The Fahrenheit temperature ϑ_0 = **0** °F expresses the same temperature as the thermodynamic temperature $T_{0,F}$ = 459.67 °R.

* The 13th General Conference of Weights and Measures[3] in October 1967 abrogated the names and symbols previously used – including the degree Kelvin (°K) and degree (deg, for temperature interval or difference) – but agreed that the formulations resulting from the earlier usage should be admitted for the time being. In this chapter on 'Units of Measurement' the text conforms with the new definition of the kelvin (K) but in other chapters of these *Scientific Tables* the old usage is followed.

When expressing a temperature interval or difference $\Delta\theta = \theta_1 - \theta_2$ the degree Fahrenheit is usually written degF (= degR)

Conversion of temperature units and values

(a) Between temperature interval units:

$$1\ \mathrm{degR} = 1\ \mathrm{degF} = \frac{5}{9}\ \mathrm{K} = \frac{5}{9}\ ^\circ\mathrm{C}$$

$$1\ \mathrm{K} = 1\ ^\circ\mathrm{C} = \frac{9}{5}\ \mathrm{degR} = \frac{9}{5}\ \mathrm{degF}$$

(b) For temperature values on the four thermodynamic scales ($T = T_K\,\mathrm{K} = T_R\,^\circ\mathrm{R}$; $t = t_C\,^\circ\mathrm{C}$, $\theta = \theta_F\,^\circ\mathrm{F}$):

$$T_K = \frac{5}{9}T_R = t_C + 273.15 = \frac{5}{9}(\theta_F + 459\ 67)$$

$$T_R = \frac{9}{5}T_K = \theta_F + 459\ 67 = \frac{9}{5}t_C + 491.67$$

$$t_C = T_K - 273\ 15 = \frac{5}{9}(T_R - 491\ 67) = \frac{5}{9}(\theta_F - 32)$$

$$\theta_F = T_R - 459\ 67 = \frac{9}{5}T_K - 459\ 67 = \frac{9}{5}t_C + 32$$

Fundamental points of the thermodynamic temperature scales

Unit	Symbol	Temperature value at absolute zero	Temperature value at triple point of water*
kelvin	K	0	273 16
degree Celsius	°C	− 273 15	0 01
degree Rankine	°R	0	491 688
degree Fahrenheit	°F	− 459 67	32.018

* Temperature at which the solid, liquid and gaseous phases of water are in equilibrium.

[illegible] point of water and the absolute zero, which is very near to the old definition, means that the temperatures of the ice and steam point are now values that must be determined experimentally

International Practical Temperature Scale of 1968 (IPTS-68)

[illegible]

The IPTS-68 is based on the assigned values of the temperatures (columns 2 and 3 of the table below) of a number of reproducible equilibrium states (defining fixed points, column 1 of the table) and on standard instruments calibrated at these temperatures Interpolation between the fixed point temperatures is effected by means [illegible] the case of T and t

The defining fixed points are established by realizing specified equilibrium states between phases of pure substances The standard instruments and interpolation formulae are as follows in the range 13 81 K $\leq T_{68} \leq$ 730 89 K (freezing point of antimony as a secondary reference point) the platinum resistance thermometer, in the range 730 89 K $\leq T_{68} \leq$ 1337 58 K the platinum–10% rhodium/platinum thermocouple, in the range above 1337.58 K the PLANCK law for radiation in terms of spectral concentration of radiance $L_{e\lambda}$ (see page 222), with 1337 58 K as reference temperature and the value 0 014 388 m K for the 2nd PLANCK radiation constant c_2 (see page 228)

The IPTS-68 has been chosen in such a way that temperature measured on it closely approximates to thermodynamic temperature $T_{68} = T + \Delta T_{68} \approx T$ and $t_{68} = t + \Delta t_{68} \approx t$. The difference is within the present limits of accuracy of measurement (see column 4 of the table) At the triple point of water both temperature values are exactly equal by definition.

Defining fixed points of the IPTS-68, values assigned to T_{68} and t_{68}, and estimated uncertainties $\Delta T_{68} = \Delta t_{68}$

Defining fixed point (equilibrium state*)	Assigned value T_{68} in K	Assigned value t_{68} in °C	$\Delta T_{68} = \Delta t_{68}$
Triple point of equilibrium hydrogen	13 81	− 259 34	± 0 01 K
25/76 standard atmosphere point of equilibrium hydrogen	17 042	− 256 108	± 0 01 K
Boiling point of equilibrium hydrogen	20 28	− 252 87	± 0 01 K
Boiling point of neon	27 102	− 246 048	± 0 01 K
Triple point of oxygen	54 361	− 218 789	± 0 01 K
Boiling point of oxygen	90 188	− 182 962	± 0 01 K
Triple point of water***	273 16	0 01	(exact by definition)
Boiling point of water** ***	373 15	100	± 0 005 K
Freezing point of zinc	692 73	419 58	± 0 03 K
Freezing point of silver	1235 08	961 93	± 0 2 K
Freezing point of gold	1337.58	1064 43	± 0 2 K

* [illegible] alternative to the boiling point of water

*** The water used should have the isotopic composition of ocean water

Practical scales of temperature (outside the IPTS-68 range) for use over the range 0.2 K–5.2 K[5]

Temperatures can be derived from measured vapour pressures of ^{4}He and ^{3}He The upper limits for use are set by the critical points of the gases (5 2 K for ^{4}He and 3 3 K for ^{3}He) and the lower limits by the minimum vapour pressure capable of practical measurement. On these scales – the '1958 ^{4}He Scale' and the '1962 ^{3}He Scale' – [illegible] vapour pressures versus temperature[6]. The '1962 ^{3}He Scale', re- [illegible]

References

[1] Cf De Boer, J , *Metrologia*, 1, 158 (1965)

[2] Conférence Générale des Poids et Mesures, *Comptes rendus des séances de la 10e Conférence générale des Poids et Mesures*, Paris 1954, Gauthier-Villars, Paris, 1955, page 79

[3] Conférence Générale des Poids et Mesures, *Comptes rendus des séances de la 13e Conférence générale des Poids et Mesures*, Paris 1967/1968, Bureau International des Poids et Mesures, Sevres, 1969 Résolutions 3, 4 and 8, pages 18, 19 60 [illegible]

Density ($\varrho = m/V$)

Dimension = $\mathsf{L^{-3}M}$

Coherent units

International System of Units kilogramme/cubic metre (kg m^{-3})
CGS system: gramme/cubic centimetre (g cm^{-3})
ft-lb-s system pound per cubic foot (lb ft^{-3})

The *density* (ϱ) of a substance is the ratio of its mass to its volume Density is dependent on both temperature [illegible]

Important density constants are the maximum density of air-free water[1] at 760 torr (i.e., at ≈ 4 °C): $\varrho_{max}(H_2O) = 0.999972$ kg dm^{-3} and the standard density of mercury: $\varrho_n(Hg) = 13.59508$ kg dm^{-3} [2].

The product of the density ϱ and the (local) acceleration due to gravity g is the specific weight ($\gamma = \varrho\, g$) of the substance. Specific weight is thus dependent not only on thermodynamic variables but also on the acceleration due to gravity, so that unlike density it is not in fact a *specific* property of a substance.

The *relative density* (d) of a substance is the ratio of its density to that of a reference substance. As the ratio of two quantities with the same dimensions it is a dimensionless quantity. Relative density is still often given the name 'specific gravity', but this is a term open to the same objection as specific weight. The usual reference density for liquids and solids is the maximum density of water, for gases the standard density of dry air free of carbon dioxide ($\varrho_n = 1.2928 \times 10^{-3}$ kg dm^{-3})[3].

Since the maximum density of water is very nearly equal to 1 kg dm^{-3} relative, density in practice can usually be equated numerically with density expressed in kg dm^{-3}. Since relative density is the ratio of two densities, two particular temperatures must be specified. Thus the relative density of a substance at 20 °C/4 °C is the ratio

$$\frac{\text{density of the substance at } 20\,°\text{C}}{\text{density of water at } 4\,°\text{C}}$$

written as d_4^{20}.

Conversion of metric units of density

A		B: 1 A unit = b B units (b in the table)	
Name	Symbol	mg mm^{-3} g cm^{-3} kg dm^{-3}	mg cm^{-3} g dm^{-3} kg m^{-3}
microgramme per cubic centimetre or millilitre .... milligramme per cubic decimetre or litre	µg cm^{-3} µg ml^{-1} mg dm^{-3} mg l^{-1}	10^{-6}	10^{-3}
milligramme per cubic centimetre or millilitre .... gramme per cubic decimetre or litre .... kilogramme per cubic metre..	mg cm^{-3} mg ml^{-1} g dm^{-3} g l^{-1} kg m^{-3}	10^{-3}	1
picogramme per cubic micrometre .... milligramme per cubic millimetre or microlitre .... gramme per cubic centimetre or millilitre .... kilogramme per cubic decimetre or litre	pg µm^{-3} mg mm^{-3} mg µl^{-1} g cm^{-3} g ml^{-1} kg dm^{-3} kg l^{-1}	1	10^3

Conversion of Anglo-Saxon units of density

A		B: 1 A unit = b B units (b in the table)	
Name	Symbol	lb ft^{-3}	kg m^{-3}
pound per cubic foot ...	lb ft^{-3}	1	1.60185×10
pound per gallon (UK) .	lb gal(UK)$^{-1}$	6.22883	9.97764×10
pound per gallon (US) .	lb gal(US)$^{-1}$	1728/231	1.19826×10^2

References

[1] Comité International des Poids et Mesures, *Proc.-Verb.Com.int.Poids Mes.* (2), 22, 77 (1950); Stille, U., *Messen und Rechnen in der Physik*, 2nd ed., Vieweg, Braunschweig, 1961, page 286.

[2] Cook and Stone, *Phil. Trans. Roy. Soc.*, 250A, 279 (1957); Cook, A. H., *Phil. Trans. Roy. Soc.*, 254A, 125 (1961); Beattie et al., *Proc. Amer. Acad. Arts Sci.*, 74, 371 (1941).

[3] Otto and Thomas, in Hausen, H. (Ed.), *Landolt-Börnstein, Physikalisch-chemische Tabellen*, 6th ed., vol. 4, part 4, section a, Springer, Berlin, 1967, page 174; Din, F., *Thermodynamic Functions of Gases*, vol. 2, Butterworth, London, 1956.

Linear velocity (u or $v = ds/dt$; s = distance)

Dimension = LT^{-1}

Coherent units

International System of Units: metre per second (m s^{-1})
CGS system: centimetre per second (cm s^{-1})
ft-lb-s system: foot per second (ft s^{-1})

Conversion of metric units of velocity

A		B: 1 A unit = b B units (b in the table)		
Name	Symbol	m min^{-1}	km h^{-1}	m s^{-1}
centimetre per second	cm s^{-1}	6×10^{-1}	3.6×10^{-2}	10^{-2}
metre per minute	m min^{-1}	1	6×10^{-2}	$1.\dot{6} \times 10^{-2}$
kilometre per hour	km h^{-1}	$1.\dot{6} \times 10$	1	$2.\dot{7} \times 10^{-1}$
metre per second	m s^{-1}	6×10	3.6	1
kilometre per second	km s^{-1}	6×10^4	3.6×10^3	10^3

Conversion of Anglo-Saxon units of velocity

A		B: 1 A unit = b B units (b in the table)		
Name	Symbol	ft s^{-1}	mile h^{-1}	m s^{-1}
foot per minute .	ft min^{-1}	$1.\dot{6} \times 10^{-2}$	$1.1\dot{3}\dot{6} \times 10^{-2}$	5.08×10^{-3}
foot per second .	ft s^{-1}	1	$6.\dot{8}\dot{1} \times 10^{-1}$	3.048×10^{-1}
mile per hour	mile h^{-1}	$1.4\dot{6}$	1	4.4704×10^{-1}
knot, nautical mile per hour ..	kn = n mile/h	1.68781	1.15078	$5.1\dot{4} \times 10^{-1}$
knot (UK), nautical mile (UK) per hour ..	kn (UK) = n mile (UK)/h	1.68889	$1.1\dot{5}$	5.14772×10^{-1}
mile per second .	mile s^{-1}	5.28×10^3	3.6×10^3	1.609344×10^3

Angular velocity ($\omega = d\varphi/dt$)

Dimension = L^0 T^{-1}

SI unit: radian per second (rad s^{-1})

Conversion of units of angular velocity

A		B: 1 A unit = b B units (b in the table)		
Name	Symbol	^{g} s^{-1}	° s^{-1}	rad s^{-1}
grade per minute ..	^{g} min^{-1}	$1.\dot{6} \times 10^{-2}$	1.5×10^{-2}	2.61799×10^{-4}
degree per minute ..	° min^{-1}	$1.\dot{8}\dot{5}\dot{1} \times 10^{-2}$	$1.\dot{6} \times 10^{-2}$	2.90888×10^{-4}
grade per second ..	^{g} s^{-1}	1	9×10^{-1}	1.57080×10^{-2}
radian per minute ..	rad min^{-1}	1.06103	9.54930×10^{-1}	$1.\dot{6} \times 10^{-2}$
degree per second ..	° s^{-1}	$1.\dot{1}$	1	1.74533×10^{-2}
radian per second ..	rad s^{-1} ..	6.36620×10	5.72958×10	1

Acceleration ($a = dv/dt$)

Dimension = LT^{-2}

Coherent units

International System of Units: metre per second squared (m s^{-2})
CGS system: centimetre per second squared (cm s^{-2}) = galileo (Gal) (for acceleration due to gravity)
ft-lb-s system: foot per second squared (ft s^{-2})

The internationally accepted value[1] of the normal acceleration due to gravity (see also page 230) is

$g_n = 9\ 806\,65\ \mathrm{m\,s^{-2}} = 980\ 665\ \mathrm{Gal\ (cm\,s^{-2})}$
$\approx 32\ 17405\ \mathrm{ft\,s^{-2}}$

Conversion of metric units of acceleration

		1 **A** unit = *b* **B** units (*b* in the table)		
A		**B**		
Name	Symbol	Gal = $\mathrm{cm\,s^{-2}}$	$\mathrm{km\,h^{-1}\,s^{-1}}$	$\mathrm{m\,s^{-2}}$
galileo . . . . . . centimetre per second squared . . .	Gal } $\mathrm{cm\,s^{-2}}$ }	1	$3\ 6 \times 10^{-2}$	10^{-2}
kilometre per hour per second	$\mathrm{km\,h^{-1}\,s^{-1}}$	$2\ 7 \times 10$	1	$2\ 7 \times 10^{-1}$
metre per second squared . .	$\mathrm{m\,s^{-2}}$	10^{2}	$3\ 6$	1

Conversion of Anglo-Saxon units of acceleration

		1 **A** unit = *b* **B** units (*b* in the table)		
A		**B**		
Name	Symbol	$\mathrm{ft\,s^{-2}}$	$\mathrm{mile\,h^{-1}\,s^{-1}}$	$\mathrm{m\,s^{-2}}$
foot per second squared	$\mathrm{ft\,s^{-2}}$	1	$6\ 81 \times 10^{-1}$	$3\ 048 \times 10^{-1}$
mile per hour per second	$\mathrm{mile\,h^{-1}\,s^{-1}}$	$1\ 46$	1	$4\ 470\,4 \times 10^{-1}$

Reference

[1] Conférence Générale des Poids et Mesures, *Comptes rendus des séances de la 3e Conférence générale des Poids et Mesures*, Paris 1901, Gauthier-Villars, Paris, 1901, page 70

Force (F) (= mass × acceleration)

Dimension = $\mathrm{L\,M\,T^{-2}}$

Coherent units

International System of Units newton (N) = $\mathrm{m\,kg\,s^{-2}} = 10^{5}$ dyn
CGS system dyne (dyn) = $\mathrm{cm\,g\,s^{-2}} = 10^{-5}$ N
ft-lb-s system poundal (pdl) = $\mathrm{ft\,lb\,s^{-2}}$ = 0 138254954376 N

Noncoherent 'technical' units of force

In technology many units of force are still in use in which the mass unit (kilogramme, pound, etc) is multiplied not by the coherent unit of acceleration ($1\ \mathrm{m\,s^{-2}}$, $1\ \mathrm{ft\,s^{-2}}$, etc.) but by the standard [illegible] will in due course cease to be used In scientific work they should in any case be avoided. In some countries, particularly France, they are no longer statutory units

Reference

[1] Deutscher Normenausschuß, *Masse, Gewicht, Gewichtskraft, Fallbeschleunigung Begriffe*, DIN 1305, June 1968, Beuth Vertrieb, Berlin, 1968

Angular acceleration ($\alpha = \mathrm{d}\omega/\mathrm{d}t = \mathrm{d}^2\varphi/\mathrm{d}t^2$)

Dimension = $\mathrm{L^0\,T^{-2}}$

SI unit: radian per second squared ($\mathrm{rad\,s^{-2}}$)

Conversion of units of angular acceleration

		1 **A** unit = *b* **B** units (*b* in the table)		
A		**B**		
Name	Symbol	${}^{g}\,\mathrm{s^{-2}}$	$°\,\mathrm{s^{-2}}$	$\mathrm{rad\,s^{-2}}$
grade per second squared .	${}^{g}\,\mathrm{s^{-2}}$	1	9×10^{-1}	$1\ 570\ 80 \times 10^{-2}$
degree per second squared	$°\,\mathrm{s^{-2}}$	1 1	1	$1\ 745\ 33 \times 10^{-2}$
radian per second squared	$\mathrm{rad\,s^{-2}}$	$6\ 366\ 20 \times 10$	$5\ 729\ 58 \times 10$	1

Conversion of noncoherent units of force (g_n = standard acceleration due to gravity = $9\ 806\,65\ \mathrm{m\,s^{-2}} = 32\ 174\,048\ \mathrm{ft\,s^{-2}}$)

			1 **A** unit = *b* **B** units (*b* in the table)	
A			**B**	
Name	Symbol	Definition	pdl	N
grain-force	grf	$g_n \times (1\ \mathrm{gr})$	$4\ 596\ 29 \times 10^{-3}$	$6\ 354\ 60 \times 10^{-4}$
pond gramme force	p gf	} $g_n \times (1\ \mathrm{g})$	$7\ 093\ 16 \times 10^{-2}$	$9\ 806\ 65 \times 10^{-3}$
pound-force	lbf	$g_n \times (1\ \mathrm{lb})$	$3\ 217\ 40 \times 10$	$4\ 448\ 22$
kilopond kilogramme force	kp kgf	} $g_n \times (1\ \mathrm{kg})$	$7\ 093\ 16 \times 10$	$9\ 806\ 65$
short ton force	sh tnf	$g_n \times (1\ \mathrm{sh\ tn})$	$6\ 434\ 81 \times 10^{4}$	$8\ 896\ 44 \times 10^{3}$
ton force (UK) long ton force (US) }	tonf	} $g_n \times (1\ \mathrm{ton})$	$7\ 206\ 99 \times 10^{4}$	$9\ 964\ 02 \times 10^{3}$

Pressure (p) (= force/area)

Dimension = $\mathrm{L^{-1}\,M\,T^{-2}}$

Coherent units

International System of Units: newton per square metre ($\mathrm{N\,m^{-2}}$) = $\mathrm{m^{-1}\,kg\,s^{-2}}$ = 10 dyn $\mathrm{cm^{-2}}$
CGS system dyne per square centimetre (dyn $\mathrm{cm^{-2}}$) = $\mathrm{cm^{-1}\,g\,s^{-2}}$ = 0 1 $\mathrm{N\,m^{-2}}$
ft lb-s system poundal per square foot (pdl $\mathrm{ft^{-2}}$) = $\mathrm{ft^{-1}\,lb\,s^{-2}}$ = 1 488 163 943 $\mathrm{N\,m^{-2}}$

Noncoherent metric units of pressure

The 10^{6} multiple of the dyn $\mathrm{cm^{-2}}$ is known as the *bar* (bar).

1 bar = 10^{3} millibar (mbar) = $10^{5}\ \mathrm{N\,m^{-2}}$ = 10^{6} dyn $\mathrm{cm^{-2}}$
= 10^{6} microbar (μbar)

The millibar is now the internationally accepted unit of pressure in meteorology*, the microbar is used in acoustics for sound pressure data

* In meteorology the millibar is widely, but wrongly, denoted by the symbol mb, the recognized symbol for millibarn (see page 202)

Conversion of metric units of pressure

A		1 **A** unit = b **B** units (b in the table)			
		B			
Name	Symbol	dyn cm^{-2} = μbar	N m^{-2}	mbar	bar
dyne per square centimetre ...... microbar	dyn cm^{-2} μbar	1	10^{-1}	10^{-3}	10^{-6}
newton per square metre	N m^{-2}	10	1	10^{-2}	10^{-5}
millibar	mbar	10^{3}	10^{2}	1	10^{-3}
bar	bar	10^{6}	10^{5}	10^{3}	1

Noncoherent 'technical' units of pressure

These are derived from the 'technical' units of force and the units of area. The *technical atmosphere* (at) is widely used:

$$1 \text{ at} = 10^4 \text{ kilopond/square metre (kp m}^{-2}\text{)}$$
$$= 1 \text{ kilopond/square centimetre (kp cm}^{-2}\text{)}$$
$$= 9.806\,65 \times 10^4 \text{ N m}^{-2} = \frac{9.806\,65 \times 10^4}{1.013\,25 \times 10^5} \text{ atm}$$
$$= 0.967\,841\,105 \text{ atm}$$

Noncoherent special units of pressure

Standard physical atmosphere (atm). Defined in connection with the International Practical Scale of Temperature of 1948[7] as

$$1 \text{ atm} = 101\,325 \text{ N m}^{-2} = 1\,013\,250 \text{ dyn cm}^{-2}$$

Torr (torr). Defined as
$1 \text{ torr} = 1 \text{ atm}/760 = 133.322\,368 \text{ N m}^{-2} = 1333.223\,68 \text{ dyn cm}^{-2}$

*Millimetre of water** (mm water). Defined as the pressure exerted by a column of water 1 mm in height at its maximum density ($0.999\,972 \text{ g cm}^{-3}$) at standard pressure (760 torr) under the standard acceleration due to gravity g_n:

$$1 \text{ mm water} = 0.1 \text{ cm} \times 0.999\,972 \text{ g cm}^{-3} \times 980.665 \text{ cm s}^{-2}$$
$$= 9.806\,375\,41 \text{ N m}^{-2} = 98.063\,754\,1 \text{ dyn cm}^{-2}$$

*Conventional millimetre of water** (mmH_2O). Defined as the pr sure exerted by a column of liquid 1 mm in height with a dens of 1 g cm^{-3} under the standard acceleration due to gravity g_n:

$$1 \text{ mmH}_2\text{O} = 0.1 \text{ cm} \times 1 \text{ g cm}^{-3} \times 980.665 \text{ cm s}^{-2}$$
$$= 9.806\,65 \text{ N m}^{-2} = 98.066\,5 \text{ dyn cm}^{-2} = 1 \text{ kp m}^{-}$$

In practice this definition is based on a column of water 1 mm height at 4 °C at standard pressure.

*Conventional millimetre of mercury** (mmHg). In accordance wi the International Barometric Conventions of the World Meteor logical Organization[2] this is defined as the pressure exerted by column of liquid 1 mm in height with a density of 13.595 1 g cm under the standard acceleration due to gravity g_n:

$$1 \text{ mmHg} = 0.1 \text{ cm} \times 13.595\,1 \text{ g cm}^{-3} \times 980.665 \text{ cm s}^{-2}$$
$$= 133.322\,387 \text{ N m}^{-2} = 1\,333.223\,87 \text{ dyn cm}^{-2}$$
$$= 1.000\,000\,14 \text{ torr}$$

In practice this definition is based with adequate accuracy on column of mercury 1 mm in height at 0 °C at standard pressu ($1 \text{ atm} = 101\,325 \text{ N m}^{-2}$).

The noncoherent Anglo-Saxon units of pressure, convention inch of water (inH_2O), conventional foot of water (ftH_2O) an conventional inch of mercury (inHg), are defined by the formul given for conventional millimetre of water and conventional mill metre of mercury by replacing the metric length unit (0.1 cm) b 1 inch or 1 foot.

For very precise measurements the unit torr is now preferred t the mmHg since unlike the latter the torr is independent of materi constants.

Standard pressure in both physics and meteorology is $101\,325 \text{ N m}^{-}$ $= 1 \text{ atm} = 760$ torr. It is roughly the mean atmospheric pressure a sea level under the standard acceleration due to gravity.

* The names of these units of pressure actually signify the height h at whic the barometer liquid with density ϱ under the acceleration due to gravity exerts the pressure $p = g\,h\,\varrho$.

Conversion of noncoherent units of pressure

A		1 **A** unit = b **B** units (b in the table)		
		B		
Name	Symbol	atm	pdl ft^{-2}	N m^{-2}
millimetre of water	mm water	$9.678\,14 \times 10^{-5}$	6.589 58	9.806 38
kilopond per square metre .... kilogramme-force per square metre	kp m^{-2} kgf m^{-2}	$9.678\,41 \times 10^{-5}$	6.589 76	9.806 65
pound-force per square foot	lbf ft^{-2}	$4.725\,41 \times 10^{-4}$	$3.217\,40 \times 10$	$4.788\,03 \times 10$
torr	torr	$1.315\,79 \times 10^{-3}$	$8.958\,85 \times 10$	$1.333\,22 \times 10^{2}$
conventional inch of water	inH$_2$O	$2.458\,32 \times 10^{-3}$	$1.673\,80 \times 10^{2}$	$2.490\,89 \times 10^{2}$
conventional foot of water	ftH$_2$O	$2.949\,98 \times 10^{-2}$	$2.008\,56 \times 10^{3}$	$2.989\,07 \times 10^{3}$
conventional inch of mercury	inHg	$3.342\,11 \times 10^{-2}$	$2.275\,55 \times 10^{3}$	$3.386\,39 \times 10^{3}$
pound-force per square inch	lbf in^{-2}	$6.804\,60 \times 10^{-2}$	$4.633\,06 \times 10^{3}$	$6.894\,76 \times 10^{3}$
technical atmosphere	at	$9.678\,41 \times 10^{-1}$	$6.589\,76 \times 10^{4}$	$9.806\,65 \times 10^{4}$
physical atmosphere	atm	1	$6.808\,73 \times 10^{4}$	$1.013\,25 \times 10^{5}$
ton-force per square foot	tonf ft^{-2}	1.058 49	$7.206\,99 \times 10^{4}$	$1.072\,52 \times 10^{5}$

References

[1] Conférence Générale des Poids et Mesures, *Comptes rendus des séances de la 9e Conférence générale des Poids et Mesures*, Paris 1948, Gauthier-Villars, Paris, 1949, pages 57 and 89; *Comptes rendus des séances de la 10e Conférence générale des Poids et Mesures*, Paris 1954, Gauthier-Villars, Paris, 1955, page 79.

[2] World Meteorological Organization, *International Barometric Conventions*, in British Standards Institution, *Barometer Conventions and Tables*, B.S. 2520: 1954, and in STILLE, U., *Messen und Rechnen in der Physik*, 2nd ed., Vieweg, Braunschweig, 1961.

Energy, Work, Amount of heat

Dimension = L^2MT^{-2}

Coherent units

International System of Units: joule (J) = newton × metre = $m^2 \text{ kg s}^{-2} = 10^7$ erg = watt second (Ws) (for W see under 'Power', page 214)
CGS system: erg (erg) = dyne × centimetre = $\text{cm}^2 \text{ g s}^{-2} = 10^{-7}$ J
ft-lb-s system: foot poundal (ft pdl) = $\text{ft}^2 \text{ lb s}^{-2}$
$= 0.042\,140\,110\,1$ J

Symbols

Energy = E, W
Potential energy = E_p, V, Φ
Kinetic energy = E_k, T, K
Work = W, A
Amount of heat = Q
Radiant energy = Q, Q_e, W (see also page 222)

Energy, *work* and *amount of heat* are physical quantities with the same dimensions and ideally should be measured in a common unit. In the International System of Units this simplification has

onversion of noncoherent units of energy

A		1 **A** unit = *b* **B** units (*b* in the table)		
		B		
Name	Symbol	kWh	ft pdl	J
foot pound-force	ft lbf	3 766 16 × 10^{-7}	3 217 40 × 10	1 355 82
thermochemical calorie	$cal_{thermochem}$	1 162 × 10^{-6}	9 928 78 × 10	4 184
15° calorie	cal_{15}	1 162 6 × 10^{-6}	9 932 34 × 10	4 185 5
International Steam Table calorie	cal_{IT}	1 163 × 10^{-6}	9 935 43 × 10	4 186 8
kilopond metre, kilogramme-force mètre	kp m = kgf m	2 724 07 × 10^{-6}	2.327 15 × 10^{2}	9 806 65
litre atmosphere	*l* atm	2.814 58 × 10^{-5}	2 404 48 × 10^{3}	1 013 25 × 10^{2}
British thermal unit	Btu	2 930 71 × 10^{-4}	2 503 69 × 10^{4}	1 055 06 × 10^{3}
horsepower-hour	hph	7 457 00 × 10^{-1}	6 370 46 × 10^{7}	2 684 52 × 10^{6}
metric horsepower hour	ch or PSh	7 354 987 5 × 10^{-1}	6 283 31 × 10^{7}	2 647 80 × 10^{6}
kilowatt hour	kWh	1	8 542 93 × 10^{7}	3 6 × 10^{6}

Conversion of units of energy used in atomic physics[2 7]

A			1 **A** unit equals or corresponds to *b* **B** units (*b* in the table)		
			B		
Name	Identifying formula	Symbol	g	J	erg
gramme	$\triangleq E(\mathrm{g}) = c^2 \times (1\mathrm{g})$	g	1	8 987 554 × 10^{13}	8 987 554 × 10^{20}
joule		J	1 112 6 × 10^{-14}	1	1 × 10^{7}
erg		erg	1 112 6 × 10^{-21}	1 × 10^{-7}	1
atomic mass unit	$\triangleq E(\mathrm{u}) = c^2 \times (1\,\mathrm{u})$	u	1 660 4 × 10^{-24}	1 492 32 × 10^{-10}	1 492 32 × 10^{-3}
rydberg	hcR_∞	Ry	2 425 3 × 10^{-32}	2 179 71 × 10^{-18}	2.179 71 × 10^{-11}
electronvolt	$e \times (1\mathrm{V})$	eV	1 782 6 × 10^{-33}	1 602 10 × 10^{-19}	1 602 10 × 10^{-12}
centimetre^{-1}	$\triangleq E(\mathrm{cm}^{-1}) = hc \times (1\,\mathrm{cm}^{-1})$	cm^{-1}	2.210 1 × 10^{-37}	1 986 30 × 10^{-23}	1 986 30 × 10^{-16}
kelvin	$\triangleq E(\mathrm{K}) = \mathrm{k} \times (1\,\mathrm{K})$	K	1 536 1 × 10^{-37}	1.380 54 × 10^{-23}	1.380 54 × 10^{-16}
second^{-1}	$\triangleq E(\mathrm{s}^{-1}) = h \times (\mathrm{s}^{-1})$	s^{-1}	7 372 0 × 10^{-48}	6 625 59 × 10^{-34}	6 625 59 × 10^{-27}
Name	Identifying formula	Symbol	u	Ry	eV
gramme	$\triangleq E(\mathrm{g}) = c^2 \times (1\mathrm{g})$	g	6 022 5 × 10^{23}	4 123 3 × 10^{31}	5 609 85 × 10^{32}
joule		J	6 701 0 × 10^{9}	4 587 8 × 10^{17}	6 241 81 × 10^{18}
erg		erg	6 701 0 × 10^{2}	4 587 8 × 10^{10}	6 241 81 × 10^{11}
atomic mass unit	$\triangleq E(\mathrm{u}) = c^2 \times (1\,\mathrm{u})$	u	1	6 846 4 × 10^{7}	9 314 78 × 10^{8}
rydberg	hcR_∞	Ry	1 460 6 × 10^{-8}	1	1 360 54 × 10
electronvolt	$e \times (1\mathrm{V})$	eV	1 073 6 × 10^{-9}	7 350 0 × 10^{-2}	1
centimetre^{-1}	$\triangleq E(\mathrm{cm}^{-1}) = hc \times (1\,\mathrm{cm}^{-1})$	cm^{-1}	1 331 0 × 10^{-13}	9 112 7 × 10^{-6}	1 239 81 × 10^{-4}
kelvin	$\triangleq E(\mathrm{K}) = \mathrm{k} \times (1\,\mathrm{K})$	K	9 250 9 × 10^{-14}	6 333 6 × 10^{-6}	8 617 06 × 10^{-5}
second^{-1}	$\triangleq E(\mathrm{s}^{-1}) = h \times (\mathrm{s}^{-1})$	s^{-1}	4 439 8 × 10^{-24}	3 039 7 × 10^{-16}	4 135 56 × 10^{-15}
Name	Identifying formula	Symbol	cm^{-1}	K	s^{-1}
gramme	$\triangleq E(\mathrm{g}) = c^2 \times (1\mathrm{g})$	g	4 524 8 × 10^{36}	6 510 2 × 10^{36}	1 356 5 × 10^{47}
joule		J	5 034 5 × 10^{22}	7 243 5 × 10^{22}	1 509 3 × 10^{33}
erg		erg	5 034 5 × 10^{15}	7 243 5 × 10^{15}	1 509 3 × 10^{26}
atomic mass unit	$\triangleq E(\mathrm{u}) = c^2 \times (1\,\mathrm{u})$	u	7 513 1 × 10^{12}	1 081 0 × 10^{13}	2 252 4 × 10^{23}
rydberg	hcR_∞	Ry	1 097 4 × 10^{5}	1 578 9 × 10^{5}	3 289 8 × 10^{15}
electronvolt	$e \times (1\mathrm{V})$	eV	8 065 7 × 10^{3}	1 160 5 × 10^{4}	2 418 0 × 10^{14}
centimetre^{-1}	$\triangleq E(\mathrm{cm}^{-1}) = hc \times (1\,\mathrm{cm}^{-1})$	cm^{-1}	1	1 438 8	2 997 9 × 10^{10}
kelvin	$\triangleq E(\mathrm{K}) = \mathrm{k} \times (1\,\mathrm{K})$	K	6 950 3 × 10^{-1}	1	2 083 6 × 10^{10}
second^{-1}	$\triangleq E(\mathrm{s}^{-1}) = h \times (\mathrm{s}^{-1})$	s^{-1}	3.335 6 × 10^{-11}	4 799 3 × 10^{-11}	1

now been achieved, and many of the present noncoherent 'mechanical', 'electrical' and 'caloric' units will eventually be of historical interest only This is likely to take a long time, however, since the

Noncoherent units of energy

= 1000 cal_{15}

International Steam Table calorie (cal_{IT}) In 1956 the 5th International Conference on Properties of Steam[2 3 4] redefined the International Steam Table calorie as 1 cal_{IT} = 4 186 8 J

Kilopond metre (kp m) =

= 101 327 8 J.

British thermal unit (B t.u IT = Btu) Like the Steam Table calorie this was redefined in 1956[2 3 4] (for lb see under 'Mass', page 204).

$$1\ \mathrm{Btu} = 4\ 1868\ \frac{\mathrm{degF}}{\mathrm{K}} \times \frac{\mathrm{lb}}{\mathrm{g}}\ \mathrm{J} = 2\ 326\ \frac{\mathrm{lb}}{\mathrm{g}}\ \mathrm{J}$$

Horsepower-hour (hph) = hp × h, 1 hp = 550 ft lbf s^{-1} (for lbf see under 'Force', page 211)

Metric horsepower-hour (French ch h, German PSh) = ch (or PS) × h, 1 ch (or PS) = 75 m kp s^{-1} (for kp see under 'Force', page 211).

Kilowatt hour (kWh) = kW × h, 1 W = 1 J s^{-1}

Units of energy and energy equivalents in atomic and nuclear physics

The units of energy used in atomic and nuclear physics contain one or more physical constants as factors, namely the velocity of

energy): gramme [g $\sim E$(g)], atomic mass unit [u $\sim E$(u)], centimetre^{-1} [cm^{-1} $\sim E$(cm^{-1})], kelvin [K $\sim E$(K)] and second^{-1} [s^{-1} $\sim E$(s^{-1})]. The relationships of these energy units to those used in macrophysics (joule and erg) depend numerically on the results of determinations of the atomic constants. For the physical constants and other units and measures of energy in atomic and nuclear physics see the table on pages 228 and 229.

References

[1] Conférence Générale des Poids et Mesures, *Comptes rendus des séances de la 9e Conférence générale des Poids et Mesures*, Paris 1948, Gauthier-Villars, Paris, 1949, pages 55 and 63.
[2] Stille, U., *Messen und Rechnen in der Physik*, 2nd ed., Vieweg, Braunschweig, 1961.
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[5] Comité International des Poids et Mesures, *Proc.-Verb. Com. int. Poids Mes.*, 22, 79 (1950).
[6] Schmidt, E., *Brennstoff, Wärme, Kraft*, 9, 432 (1957).
[7] Cohen and DuMond, *Rev. mod. Phys.*, 37, 537 (1965); International Union of Pure and Applied Physics, *Symbols, Units and Nomenclature in Physics*, Document U.I.P. 11 (S.U.N. 65-3), 1965, page 30.

Power (P) (= energy/time = force × velocity)

Dimension = L^2 M T^{-3}

Coherent units

International System of Units: watt (W) = joule per second = newton × metre per second = m^2 kg s^{-3} = 10^7 erg s^{-1}.
CGS system: erg per second (erg s^{-1}) = dyne × centimetre per second = cm^2 g s^{-3} = 10^{-7} W
ft-lb-s system: foot poundal per second (ft pdl s^{-1}) = ft^2 lb s^{-3} = 0.042 140 110 1 W

Conversion of noncoherent units of power

The units of power related to the second (e.g., cal$_{IT}$ s^{-1}) are converted into ft pdl s^{-1} or watt (= J s^{-1}) by means of the factors given for the conversion of the noncoherent units of energy (page 212).

1 **A** unit = b **B** units (b in the table)			
A		**B**	
Name	Symbol	ft pdl s^{-1}	W = J s^{-1}
International Steam Table calorie per hour	cal$_{IT}$ h^{-1}	2.759 84 × 10^{-2}	1.163 × 10^{-3}
British thermal unit per hour	Btu h^{-1}	6.954 68	2.930 71 × 10^{-1}
horsepower*	hp	1.769 57 × 10^4	7.457 00 × 10^2
metric horsepower*	ch or PS	1.745 37 × 10^4	7.354 9875 × 10^2

* 1 ch or PS = 75 m kp s^{-1}; 1 hp = 550 ft lbf s^{-1}.

Action (= energy × time)

Dimension = L^2 M T^{-1}

Coherent units

International System of Units: joule × second (J s) = newton × metre × second = m^2 kg s^{-1} = 10^7 erg s
CGS system: erg × second (erg s) = dyne × centimetre × second = cm^2 g s^{-1} = 10^{-7} J s
ft-lb-s system: foot poundal second (ft pdl s) = ft^2 lb s^{-1} = 0.042 140 110 1 J s

Entropy (S)

Dimension = L^2 M T^{-2} Θ^{-1}

Coherent units

International System of Units: joule per kelvin (J K^{-1}) = 10^7 erg K^{-1}

Noncoherent units

erg per kelvin (erg K^{-1}) = 10^{-7} J K^{-1}
foot poundal per degree Fahrenheit (ft pdl degF^{-1})

Viscosity

Dynamic viscosity (η)

Dimension = L^{-1} M T^{-1}

Dynamic viscosity is the property of a fluid (liquid or gas) offering resistance ('internal friction') to the non-accelerated di placement of two adjacent layers.

Coherent units

International System of Units: newton × second per squa metre (N s m^{-2}) = m^{-1} kg s^{-1} = 0.671 969 pdl s ft^{-2}

CGS system: poise (P) = dyne × second per square centimet (dyn s cm^{-2}) = cm^{-1} g s^{-1} = 10^{-1} N s m^{-2}
ft-lb-s system: poundal second per square foot (pdl s ft^{-2}) = ft^{-1} lb s^{-1} = 1.488 16 N s m^{-2}

Conversion of metric units of dynamic viscosity

		1 **A** unit = b **B** units (b in the table)				
A		**B**				
Name	Symbol	μP	mP	cP	P	N s m^{-2}
micropoise ...	μP	1	10^{-3}	10^{-4}	10^{-6}	10^{-7}
millipoise	mP	10^3	1	10^{-1}	10^{-3}	10^{-4}
centipoise	cP	10^4	10	1	10^{-2}	10^{-3}
poise	P	10^6	10^3	10^2	1	10^{-1}
newton × second per square metre	N s m^{-2}	10^7	10^4	10^3	10	1

Kinematic viscosity (ν) (= viscosity/density)

Dimension = L^2 T^{-1}

Maxwell's kinematic viscosity is the ratio of the dynamic viscosity η and the density ϱ, so that strictly speaking the term viscosity is here a misnomer. ν occurs in many flow processes, particularly when using models, as determinative magnitude (for instance in Reynold's number $Re = lu/\nu$).

Coherent units

International System of Units: square metre per second (m^2 s^{-1}) = 10.763 9 ft^2 s^{-1} = 3600 m^2 h^{-1}
CGS system: stokes (St) = square centimetre per second (cm^2 s^{-1}) = 10^{-4} m^2 s^{-1}
ft-lb-s system: square foot per second (ft^2 s^{-1}) = 9.290 30 × 10^{-2} m^2 s^{-1} = 334.451 m^2 h^{-1}

Other unit

square metre per hour (m^2 h^{-1}) = $2.\dot{7}$ × 10^{-4} m^2 s^{-1} = $2.\dot{7}$ St

Viscosity of solutions

The ratio of the viscosity of a solution η to the viscosity of the solvent η_0 is known as the *viscosity ratio* (formerly called relative viscosity) (η/η_0). The quotient $(\eta - \eta_0)/\eta_0$ is the *viscosity increment*. In dilute solutions a further important magnitude is the *viscosity number* (formerly called reduced viscosity) (I_v), dimension L^3 M^{-1}, defined as $I_v = (1/c) \times (\eta - \eta_0)/\eta_0$, where c is the mass concentration of the solution. The limiting value

$$I_0 = \lim_{\substack{c \to 0 \\ \tau \to 0}} \frac{1}{c} \times \frac{\eta - \eta_0}{\eta_0}$$

is the *limiting viscosity number* (formerly called intrinsic viscosity) (I_0) (τ = shear stress).

Coherent units for I_v and I_0

International System of Units: cubic metre per kilogramme (m^3 kg^{-1}) = 16.018 5 ft^3 lb^{-1}
CGS system: cubic centimetre per gramme (cm^3 g^{-1}) = 10^{-3} m^3 kg^{-1}
ft-lb-s system: cubic foot per pound (ft^3 lb^{-1}) = 0.062 428 0 m^3 kg^{-1}

Surface tension (σ)

Dimension = $\mathrm{M\,T^{-2}}$

Coherent units

International System of Units: newton per metre ($\mathrm{N\,m^{-1}}$)
= joule per square metre ($\mathrm{J\,m^{-2}}$) = $\mathrm{kg\,s^{-2}}$
CGS system: dyne per centimetre ($\mathrm{dyn\,cm^{-1}}$)
= erg per square centimetre ($\mathrm{erg\,cm^{-2}}$) = $\mathrm{g\,s^{-2}} = 10^{-3}\,\mathrm{N\,m^{-1}}$

Thermal conductivity (λ)

Dimension = $\mathrm{L\,M\,T^{-3}\,\Theta^{-1}}$

Coherent unit

International System of Units: watt per (metre × kelvin)
($\mathrm{W\,m^{-1}\,K^{-1}}$) = $1\,\mathrm{m\,kg\,s^{-3}\,K^{-1}}$
= $2.388\,46 \times 10^{-3}\,\mathrm{cal_{IT}\,cm^{-1}\,s^{-1}\,K^{-1}}$
= $0.859\,845\,\mathrm{kcal_{IT}\,m^{-1}\,h^{-1}\,K^{-1}}$
= $1.604\,97 \times 10^{-4}\,\mathrm{Btu\,ft^{-1}\,s^{-1}\,degF^{-1}}$

Other unit

erg per (second × centimetre × kelvin) ($\mathrm{erg\,s^{-1}\,cm^{-1}\,K^{-1}}$)
= $1\,\mathrm{cm\,g\,s^{-3}\,K^{-1}} = 10^{-5}\,\mathrm{W\,m^{-1}\,K^{-1}}$
= $2.388\,46 \times 10^{-8}\,\mathrm{cal_{IT}\,cm^{-1}\,s^{-1}\,K^{-1}}$
= $8.598\,45 \times 10^{-6}\,\mathrm{kcal_{IT}\,m^{-1}\,h^{-1}\,K^{-1}}$
= $1.604\,97 \times 10^{-9}\,\mathrm{Btu\,ft^{-1}\,s^{-1}\,degF^{-1}}$

Other units with 1 cal$_{IT}$ = 4.1868 J

calorie per (centimetre × second × kelvin) ($\mathrm{cal_{IT}\,cm^{-1}\,s^{-1}\,K^{-1}}$)
= $418.68\,\mathrm{W\,m^{-1}\,K^{-1}} = 360\,\mathrm{kcal_{IT}\,m^{-1}\,h^{-1}\,K^{-1}}$
= $0.067\,196\,9\,\mathrm{Btu\,ft^{-1}\,s^{-1}\,degF^{-1}}$
kilocalorie per (metre × hour × kelvin) ($\mathrm{kcal_{IT}\,m^{-1}\,h^{-1}\,K^{-1}}$)
= $1.163\,\mathrm{W\,m^{-1}\,K^{-1}} = 2.7 \times 10^{-3}\,\mathrm{cal_{IT}\,cm^{-1}\,s^{-1}\,K^{-1}}$

Anglo-Saxon units with 1 Btu = 2326 $\frac{\mathrm{lb}}{\mathrm{kg}}$ J = 1055.056 J

British thermal unit per foot second degree Fahrenheit
($\mathrm{Btu\,ft^{-1}\,s^{-1}\,degF^{-1}}$) = $6230.64\,\mathrm{W\,m^{-1}\,K^{-1}}$
= $3600\,\mathrm{Btu\,ft^{-1}\,h^{-1}\,degF^{-1}} = 43\,200\,\mathrm{Btu\,in\,ft^{-2}\,h^{-1}\,degF^{-1}}$
= $14.881\,6\,\mathrm{cal_{IT}\,cm^{-1}\,s^{-1}\,K^{-1}}$
British thermal unit per foot hour degree Fahrenheit
($\mathrm{Btu\,ft^{-1}\,h^{-1}\,degF^{-1}}$) = $1.730\,73\,\mathrm{W\,m^{-1}\,K^{-1}}$
= $2.7 \times 10^{-4}\,\mathrm{Btu\,ft^{-1}\,s^{-1}\,degF^{-1}} = 12\,\mathrm{Btu\,in\,ft^{-2}\,h^{-1}\,degF^{-1}}$
= $1.488\,16\,\mathrm{kcal_{IT}\,m^{-1}\,h^{-1}\,K^{-1}}$

(Surface) coefficient of heat transfer (α)
(Over-all) coefficient of heat transfer (K)

Dimension = $\mathrm{M\,T^{-3}\,\Theta^{-1}}$

Coherent unit

SI: watt per (square metre × kelvin) ($\mathrm{W\,m^{-2}\,K^{-1}}$)
= $1\,\mathrm{kg\,s^{-3}\,K^{-1}} = 2.388\,46 \times 10^{-5}\,\mathrm{cal_{IT}\,cm^{-2}\,s^{-1}\,K^{-1}}$
= $0.859\,845\,\mathrm{kcal_{IT}\,m^{-2}\,h^{-1}\,K^{-1}}$
= $4.891\,95 \times 10^{-5}\,\mathrm{Btu\,ft^{-2}\,s^{-1}\,degF^{-1}}$

Other unit

erg per (square centimetre × second × kelvin)
($\mathrm{erg\,cm^{-2}\,s^{-1}\,K^{-1}}$) = $1\,\mathrm{g\,s^{-3}\,K^{-1}} = 10^{-3}\,\mathrm{W\,m^{-2}\,K^{-1}}$
= $2.388\,46 \times 10^{-8}\,\mathrm{cal_{IT}\,cm^{-2}\,s^{-1}\,K^{-1}}$
= $8.598\,45 \times 10^{-4}\,\mathrm{kcal_{IT}\,m^{-2}\,h^{-1}\,K^{-1}}$
= $4.891\,95 \times 10^{-8}\,\mathrm{Btu\,ft^{-2}\,s^{-1}\,degF^{-1}}$

Other units with 1 cal$_{IT}$ = 4.1868 J

calorie per (square centimetre × second × kelvin)
($\mathrm{cal_{IT}\,cm^{-2}\,s^{-1}\,K^{-1}}$) = $41\,868\,\mathrm{W\,m^{-2}\,K^{-1}}$
= $36\,000\,\mathrm{kcal_{IT}\,m^{-2}\,h^{-1}\,K^{-1}} = 2.048\,16\,\mathrm{Btu\,ft^{-2}\,s^{-1}\,degF^{-1}}$
kilocalorie per (square metre × hour × kelvin)
($\mathrm{kcal_{IT}\,m^{-2}\,h^{-1}\,K^{-1}}$) = $1.163\,\mathrm{W\,m^{-2}\,K^{-1}}$
= $2.7 \times 10^{-5}\,\mathrm{cal_{IT}\,cm^{-2}\,s^{-1}\,K^{-1}}$

Anglo-Saxon units with 1 Btu = 2326 $\frac{\mathrm{lb}}{\mathrm{kg}}$ J = 1055.056 J

Electricity and magnetism (for references see page 217)

International System of Units (SI units)

The base electrical unit is that of electric current, the ampere (A), defined[1] as that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed one metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length

This theoretical definition is realized experimentally in so-called 'absolute ampere measurements' by determining the force between

... $= 4\pi \times 10^{-7}\,\mathrm{N/A^2}$

Electrodynamics is now generally described by means of the field theory (as recommended by the IUPAP[3], IEC[4], ISO[5], etc) In so

$\times 10^{-12}\,\mathrm{F\,m^{-1}}$

This system has now largely displaced the three-dimensional systems derived from three base quantities (e g , length, mass, time, dimensional system LMT) used almost exclusively in the 19th century The latter can be subdivided into 'electrical' and 'magnetic' variants, namely those with an 'electromagnetic' (general symbol X_m) and an 'electrostatic' (general symbol X_e) three-dimensional definition of quantities These variants, and the four-dimensional system, use different dimensions ε_0 and μ_0 do not appear in the equations of the three-dimensional systems, where only ε occurs

Apart from the dimensional difference between the three- and four-dimensional systems there is also the alternative between geometrically 'rationalized' and 'non-rationalized' versions The con-

Quantity (symbol)	Dimension in LMTI	SI Unit		Numerical value of X in SI unit = $b \times$ numerical value of X_m in emu = $b' \times$ numerical value of X_e in esu			
				CGS system			
				electromagnetic (X_m/emu)		electrostatic (X_e/esu)	
		Name	Symbol	emu	b *	esu	b' *
Electric potential difference (U)	$L^2MT^{-3}I^{-1}$	volt	V	$cm^{3/2}g^{1/2}s^{-2}$	10^{-8}	$cm^{1/2}g^{1/2}s^{-1}$	$\zeta \times 10^{-8}$
Electric current (I)	I	ampere	A	$cm^{1/2}g^{1/2}s^{-1}$	10	$cm^{3/2}g^{1/2}s^{-2}$	$10/\zeta$
Electric current density (J or S)	$L^{-2}I$	ampere per square metre	$A\,m^{-2}$	$cm^{-3/2}g^{1/2}s^{-1}$	10^5	$cm^{-1/2}g^{1/2}s^{-2}$	$10^5/\zeta$
Electric linear current density (A or α)	$L^{-1}I$	ampere/metre	$A\,m^{-1}$	$cm^{-1/2}g^{1/2}s^{-1}$	10^3	$cm^{1/2}g^{1/2}s^{-2}$	$10^3/\zeta$
Electric field strength (E)	$LMT^{-3}I^{-1}$	volt per metre	$V\,m^{-1}$	$cm^{1/2}g^{1/2}s^{-2}$	10^{-6}	$cm^{-1/2}g^{1/2}s^{-1}$	$\zeta \times 10^{-6}$
Electric flux density, displacement (D)	$L^{-2}TI$	coulomb per square metre	$C\,m^{-2}$	$cm^{-3/2}g^{1/2}$	$10^5/4\pi$	$cm^{-1/2}g^{1/2}s^{-1}$	$10^5/(4\pi\zeta)$
Electric (displacement) flux (Ψ)	TI	coulomb	$C(=A\,s)$	$cm^{1/2}g^{1/2}$	$10/4\pi$	$cm^{3/2}g^{1/2}s^{-1}$	$10/(4\pi\zeta)$
Electric polarization (P)	$L^{-2}TI$	coulomb per square metre	$C\,m^{-2}$	$cm^{-3/2}g^{1/2}$	10^5	$cm^{-1/2}g^{1/2}s^{-1}$	$10^5/\zeta$
Electric dipole moment (p)	LTI	coulomb × metre	C m	$cm^{3/2}g^{1/2}$	10^{-1}	$cm^{5/2}g^{1/2}s^{-1}$	$10^{-1}/\zeta$
Electric polarizability (α_e)	$M^{-1}T^4I^2$	farad × square metre	$F\,m^2$	$cm\,s^2$	10^5	cm^3	$10^5/\zeta^2$
Electric susceptibility (χ_e or χ)	$L^0M^0T^0I^0$	1	1	1	4π	1	4π
Electric charge (Q)	TI	coulomb	$C(=A\,s)$	$cm^{1/2}g^{1/2}$	10	$cm^{3/2}g^{1/2}s^{-1}$	$10/\zeta$
Volume density of electric charge, charge density (ϱ or η)	$L^{-3}TI$	coulomb per cubic metre	$C\,m^{-3}$	$cm^{-5/2}g^{1/2}$	10^7	$cm^{-3/2}g^{1/2}s^{-1}$	$10^7/\zeta$
Surface density of electric charge (σ)	$L^{-2}TI$	coulomb per square metre	$C\,m^{-2}$	$cm^{-3/2}g^{1/2}$	10^5	$cm^{-1/2}g^{1/2}s^{-1}$	$10^5/\zeta$
Capacitance (C)	$L^{-2}M^{-1}T^4I^2$	farad	$F(=A\,s\,V^{-1})$	$cm^{-1}s^2$	10^9	cm	$10^9/\zeta^2$
Electric resistance (R) (to direct current)	$L^2MT^{-3}I^{-2}$	ohm	$\Omega(=V\,A^{-1})$	$cm\,s^{-1}$	10^{-9}	$cm^{-1}s$	$\zeta^2 \times 10^{-9}$
Electric conductance (G) (to direct current)	$L^{-2}M^{-1}T^3I^2$	reciprocal ohm**	$A\,V^{-1}$	$cm^{-1}s$	10^9	$cm\,s^{-1}$	$10^9/\zeta^2$
Electric resistivity (ϱ)	$L^3MT^{-3}I^{-2}$	ohm × metre	$\Omega\,m$	cm^2s^{-1}	10^{-11}	s	$\zeta^2 \times 10^{-11}$
Electric conductivity (γ or σ)	$L^{-3}M^{-1}T^3I^2$	reciprocal ohm** per metre	$A\,V^{-1}m^{-1}$	$cm^{-2}s$	10^{11}	s^{-1}	$10^{11}/\zeta^2$
Magnetic potential difference (V)	I	ampere	A	$cm^{1/2}g^{1/2}s^{-1}$ (gilbert, Gb)	$10/4\pi$	$cm^{3/2}g^{1/2}s^{-2}$	$10/(4\pi\zeta)$
Magnetic field strength (H)	$L^{-1}I$	ampere per metre	$A\,m^{-1}$	$cm^{-1/2}g^{1/2}s^{-1}$ (oersted, Oe)†	$10^3/4\pi$	$cm^{1/2}g^{1/2}s^{-2}$	$10^3/(4\pi\zeta)$
Magnetic vector potential (A)	$LMT^{-2}I^{-1}$	weber per metre	$Wb\,m^{-1}$	$cm^{1/2}g^{1/2}s^{-1}$	10^{-6}	$cm^{-1/2}g^{1/2}$	$\zeta \times 10^{-6}$
Magnetic flux density (B) (magnetic induction)	$MT^{-2}I^{-1}$	tesla	$T(=Wb\,m^{-2})$	$cm^{-1/2}g^{1/2}s^{-1}$ (gauss, Gs)†	10^{-4}	$cm^{-3/2}g^{1/2}$	$\zeta \times 10^{-4}$
Magnetic flux (Φ)	$L^2MT^{-2}I^{-1}$	weber	Wb	$cm^{3/2}g^{1/2}s^{-1}$ (maxwell, Mx)	10^{-8}	$cm^{1/2}g^{1/2}$	$\zeta \times 10^{-8}$
Magnetization (M or H_i)	$L^{-1}I$	ampere per metre	$A\,m^{-1}$	$cm^{-1/2}g^{1/2}s^{-1}$	10^3	$cm^{1/2}g^{1/2}s^{-2}$	$10^3/\zeta$
(Electro)magnetic moment (m or μ)	L^2I	ampere × square metre	$A\,m^2$	$cm^{5/2}g^{1/2}s^{-1}$	10^{-3}	$cm^{7/2}g^{1/2}s^{-2}$	$10^{-3}/\zeta$
Magnetic susceptibility (χ_m or κ)	$L^0M^0T^0I^0$	1	1	1	4π	1	4π
Magnetic polarization (J or B_i)	$MT^{-2}I^{-1}$	tesla	$T(=Wb\,m^{-2})$	$cm^{-1/2}g^{1/2}s^{-1}$	$4\pi \times 10^{-4}$	$cm^{-3/2}g^{1/2}$	$4\pi\zeta \times 10^{-4}$
Magnetic dipole moment (p_m)	$L^3MT^{-2}I^{-1}$	weber × metre	Wb m	$cm^{5/2}g^{1/2}s^{-1}$	$4\pi \times 10^{-10}$	$cm^{3/2}g^{1/2}$	$4\pi\zeta \times 10^{-10}$
(Coulomb's) magnetic pole strength (m)	$L^2MT^{-2}I^{-1}$	weber	$Wb(=V\,s)$	$cm^{3/2}g^{1/2}s^{-1}$	$4\pi \times 10^{-8}$	$cm^{1/2}g^{1/2}$	$4\pi\zeta \times 10^{-8}$
Self inductance (L)	$L^2MT^{-2}I^{-2}$	henry	$H(=V\,s\,A^{-1})$	cm	10^{-9}	$cm^{-1}s^2$	$\zeta^2 \times 10^{-9}$
Permeance (Λ)	$L^2MT^{-2}I^{-2}$	henry	$H(=V\,s\,A^{-1})$	cm	$4\pi \times 10^{-9}$	$cm^{-1}s^2$	$4\pi\zeta^2 \times 10^{-9}$
De-electrification or demagnetization factor (N)	$L^0M^0T^0I^0$	1	1	1	$1/4\pi$	1	$1/4\pi$
Electric or magnetic force (F)††	LMT^{-2}	newton	$N(=J\,m^{-1})$	$cm\,g\,s^{-2} = dyn$	10^{-5}	$cm\,g\,s^{-2} = dyn$	10^{-5}
Electric or magnetic energy (W)††	L^2MT^{-2}	joule	$J(=VA\,s)$	$cm^2g\,s^{-2} = erg$	10^{-7}	$cm^2g\,s^{-2} = erg$	10^{-7}
Electric or magnetic energy density (w)††	$L^{-1}MT^{-2}$	joule per cubic metre	$J\,m^{-3}$	$cm^{-1}g\,s^{-2}$	10^{-1}	$cm^{-1}g\,s^{-2}$	10^{-1}
Electric or magnetic power (P)††	L^2MT^{-3}	watt	$W(=V\,A)$	$cm^2g\,s^{-3}$	10^{-7}	$cm^2g\,s^{-3}$	10^{-7}
Poynting vector (S) (surface density of power in an electromagnetic wave)	MT^{-3}	watt per square metre	$W\,m^{-2}$	$g\,s^{-3}$	10^{-3}	$g\,s^{-3}$	10^{-3}

* $\zeta = 2.997\,925 \times 10^{10}$ ($3\sigma = \pm 3 \times 10^2\,m\,s^{-1}$)
$1/\zeta = 3.335\,640 \times 10^{-11}$
$\zeta^2 = 8.987\,55 \times 10^{20}$
$1/\zeta^2 = 1.112\,650 \times 10^{-21}$
$4\pi = 1.256\,637 \times 10$

$1/4\pi = 7.957\,75 \times 10^{-2}$
$4\pi\zeta = 3.767\,304 \times 10^{11}$
$1/4\pi\zeta = 2.654\,418 \times 10^{-12}$
$4\pi\zeta^2 = 1.129\,409 \times 10^{22}$
$1/4\pi\zeta^2 = 8.854\,19 \times 10^{-23}$

** Often called 'mho'. The name siemens, adopted by the IEC in 1935, *will come up for approval* as name of the SI unit of conductance at the next General Conference of Weights and Measures.

† The names oersted and gauss are often interchanged.

†† See also under 'Force', 'Energy' and 'Power', pages 211–214.

Radioactivity

1. Basic concepts

The term *nuclide* indicates a species of atom having specified numbers of protons and neutrons in its nucleus. Nuclides of one and the same chemical element, i.e., nuclides with the same number of protons and differing only in the number of neutrons, are known as *isotopes* of the element concerned. In some nuclides various energy states of the nucleus with finite lifetimes are possible. These states are called *isomers* of the nuclide. Isomeric *nuclides* have the same numbers of protons and neutrons and differ only in their energy content and thus their lifetime.

The nature of a nuclide is indicated unambiguously by the chemical symbol of the element and the number of nucleons (sum of the protons and neutrons = mass number) shown as an upper index to the left of the element symbol (e.g., ^{14}C, ^{32}P). Additionally, the number of protons (atomic number) can be given as a lower index on the left. Isomers in an excited, metastable state are indicated by a right upper index 'm' (e.g., $^{99}Tc^{m}$).

2. Radioactivity and law of disintegration

Radioactivity is the property of certain nuclides of spontaneously emitting either particles or gamma rays from the nucleus (nuclear radiation) or X rays from the shell after capture of an electron from the shell by the nucleus (characteristic X radiation). Except for isomeric transitions, this process always results in a change in the nature of the nuclide (radioactive transformation or radioactive disintegration). Nuclides possessing this property are known as radionuclides.

It is impossible to predict the time when an individual atom will

$$-dN = \lambda N\,dt$$

If at time zero N_0 atoms of an isolated radionuclide are present the number N_t of atoms not yet disintegrated at any time t is given by

$$N_t = N_0 e^{-\lambda t}$$

In equal time intervals the number of radioactive atoms decreases by the same proportion, the time interval during which the number decreases by half is known as the *half-life* ($T_{1/2}$)

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

The reciprocal of the decay constant λ has the dimension of time and is known as the *mean lifetime* τ. τ is the time during which the number of atoms of a radionuclide falls to the fraction $1/e$ ($\approx 37\%$) of its original value.

3. Activity

The quantity $-(dN/dt) = \lambda N$, i.e., the number of radioactive transformations taking place in a sample during the time dt divided by this time interval, is called the *activity* A. It is a measure of the

The unit of activity in the International System of Units is the reciprocal second (s^{-1})*; the commonly used unit is the curie (Ci):

$1\ Ci = 3.7 \times 10^{10}\ s^{-1}$**

Decimal multiples and submultiples of the curie are

1 megacurie (MCi) $= 10^6$ Ci $= 3.7 \times 10^{16}\ s^{-1}$
1 kilocurie (kCi) $= 10^3$ Ci $= 3.7 \times 10^{13}\ s^{-1}$
1 millicurie (mCi) $= 10^{-3}$ Ci $= 3.7 \times 10^{7}\ s^{-1}$
1 microcurie (µCi) $= 10^{-6}$ Ci $= 3.7 \times 10^{4}\ s^{-1}$
1 nanocurie (nCi) $= 10^{-9}$ Ci $= 3.7 \times 10^{1}\ s^{-1}$
1 picocurie (pCi) $= 10^{-12}$ Ci $= 3.7 \times 10^{-2}\ s^{-1}$

4. Specific activity

The *specific activity a of a radioactive material* (for instance a radioactive solution) is the activity A of the radionuclide contained in it divided by the mass m of the material.

$$a = \frac{A}{m}$$

This quantity is a characteristic constant of the radionuclide expressing the maximum specific activity attainable (i.e., in the carrier free state):

$$a = \frac{\lambda N_A}{M}$$

$$= 1.63 \times 10^{13} \frac{\lambda}{A_r}\ Ci\ g^{-1}$$

where N_A is the AVOGADRO constant, M the molar mass in grams per mole (see page 227) of the radionuclide, A_r its relative atomic mass (see page 226) and λ the value of its decay constant in s^{-1}.

Table 1 Reciprocals of the specific activities of some radionuclides

Nuclide	$T_{1/2}$	$1/a$ in g Ci^{-1}
^{24}Na	14.8 h	0.000 000 11[3]
^{131}I	8.06 d	0.000 008 1
^{32}P	14 d	0.000 003 52
^{45}Ca	164 d	0.000 056 6
^{14}C	5570 a	0.187

The *activity concentration* of a radioactive material (liquid or gaseous, at a given temperature and pressure) is the ratio of the activity of the contained radionuclide to the volume of the material. The commonly used unit is the curie per litre ($Ci\ l^{-1}$) or a decimal multiple of it. A special unit of activity concentration used in balneology for the activity concentration of water containing ^{222}Rn is the eman.

1 eman $= 10^{-10}\ Ci\ l^{-1}$

The MACHE unit formerly in common use is equal to 3.64 eman.

Radiation dosimetry

A long discussion on radiological quantities and units ended provisionally in 1962 with the general acceptance of the definitions recommended by the International Comm...

...comprehensive surveys of the physical concepts and quantities in the dosimetry of ionizing radiations as well as the quantities characterizing radiation sources and radiation fields see the literature[3-5].

* In English-speaking countries other units ...

Radioactivity and Radiation Dosimetry

(For references see page 221)

1. Introductory

In accordance with the fundamental GROTTHUS-DRAPER law for radiation of any kind, when matter is traversed by energy-rich radiation only that part of the energy that is absorbed can have an action on the matter. With ionizing radiations this absorption of energy occurs in several stages[6] before it becomes evident biologically. It has been agreed internationally that 'energy imparted to matter' shall be understood to mean only that energy manifested as excitation, ionization or change in the chemical bond energy of the atoms or molecules. This dosimetrically important quantity is defined[3] as follows:

The *energy E_D imparted* by ionizing radiation to the matter in a volume is the difference between the sum E_{in} of the energies (exclusive of rest energies) of all the directly and indirectly ionizing particles which have entered the volume and the sum E_{ex} of the energies (exclusive of rest energies) of all those which have left it, minus the energy equivalent Q of any increase in rest mass that took place in nuclear or elementary particle reactions within the volume:

$$E_D = \sum E_{in} - \sum E_{ex} + \sum Q$$

Whereas there can be no confusion concerning the energy totals E_{in} and E_{ex} it is necessary in the case of Q to be quite clear as to whether the nuclear or elementary particle reaction is exothermic or endothermic, i.e., whether Q is positive or negative. For example, the absorption of a photon in the volume concerned may produce an electron pair (electron + positron), an endothermic process; for this reaction therefore $Q = +2\,m_e c^2$ (m_e is the rest mass of the electron, c the velocity of light) for each interaction.

The *absorbed dose* is the amount of energy E_D imparted to the matter divided by the mass m of the matter (see below). The most important task of dosimetry is to determine this absorbed dose, which is now regarded as the most meaningful quantity to which the observable chemical and biological effects can be related. The absorbed dose is the result of certain physical reactions between radiation and matter, reactions that are in turn dependent on the nature, intensity and spectral energy distribution of the radiation and the atomic composition of the material.

Radiation fields in the body are usually non-uniform in space as well as in time. Thus there may be non-uniform distribution of the absorbed dose at the boundary surfaces of soft tissues or bones, while the pulsed electrons from particle accelerators constitute radiation non-uniform in time. The quantities concerned must therefore be determined for regions of space or intervals of time so small that any further reduction would not appreciably change the values of the quotients measured. This requirement necessitates the use of some limiting procedure, and in the ICRU definitions[3] the quantities are presented as quotients of small differences. As the ICRU Reports[3] point out, the region of space considered also has a lower limit of size, for it must still be large enough to contain many interactions and be traversed by many particles. If it is impossible to find a mass fulfilling both these conditions the dose has to be deduced from multiple measurements involving extrapolation or averaging procedures. The symbol Δ is placed before symbols for quantities concerned in such averaging procedures.

2. Radiation field quantities

A radiation field is a region in vacuum or matter that is traversed by radiation.

2.1 Particle fluence $\quad \Phi = \dfrac{\Delta N}{\Delta a}$

where ΔN is the number of particles* entering a sphere of cross-sectional area Δa.

2.2 Particle flux density or *particle fluence rate* $\quad \varphi = \dfrac{\Delta \Phi}{\Delta t}$

where $\Delta\Phi$ is the particle fluence in time Δt.

2.3 Energy fluence $\quad \Psi = \dfrac{\Delta E_\Psi}{\Delta a}$

where ΔE_Ψ is the sum of the energies, exclusive of rest energies, of all the particles entering a sphere of cross-sectional area Δa.

* In this chapter the expression 'particle' is understood to include not only corpuscles like electrons, protons, neutrons, etc. but also photons.

2.4 Energy flux density or *energy fluence rate* $\quad \psi = \dfrac{\Delta \Psi}{\Delta t}$

where $\Delta\Psi$ is the energy fluence in the time Δt.

3. Interactions

Since the great majority of radiations used in medicine are X ra[ys,] gamma rays or electrons discussion will be limited here to the inte[r]actions of photons and electrons with matter. Neutron/matter inte[r]actions and neutron dosimetry fall outside the scope of the prese[nt] article.

3.1 When photons collide with atoms or molecules, electrons a[re] liberated (as a result of the photoelectric effect, COMPTON effect an[d] pair production) and absorb some of the energy of the photons.

Mass energy transfer coefficient $\quad \dfrac{\mu_K}{\varrho} = \dfrac{1}{E\varrho} \cdot \dfrac{\Delta E_K}{\Delta l}$

where ΔE_K is the sum of the kinetic energies of the secondary elec[-] trons liberated in a layer of thickness Δl and density ϱ, and E is th[e] sum of the energies (excluding rest energies) of the photons inci[-] dent normally upon the layer.

3.2 When charged particles collide with atoms or molecules, par[t] of their kinetic energy is lost in collisions with atoms or molecule[s] due to ionization, electronic excitation and production of brems[-] strahlung.

Mass stopping power $\quad \dfrac{S}{\varrho} = \dfrac{1}{\varrho} \cdot \dfrac{\Delta E}{\Delta l}$

where ΔE is the average amount of energy lost by a charged particle of energy E when traversing a path of length Δl in a layer of density ϱ.

S_e/ϱ = electron mass stopping power

4. Quantities and units of dose

4.1 Absorbed dose and absorbed dose rate

4.1.1 The *absorbed dose** D produced by ionizing radiation in matter is the quotient of ΔE_D by Δm, where ΔE_D is the energy imparted by the radiation to the matter in a volume element and $\Delta m = \varrho \times \Delta V$ is the mass of the matter in that volume element:

$$D = \frac{\Delta E_D}{\Delta m} = \frac{1}{\varrho} \cdot \frac{\Delta E_D}{\Delta V}$$

The expression 'integral absorbed dose' still in common use thus simply means the amount of energy imparted to matter (see under 1. above):

$$E_D = \sum_i (D_i \cdot \Delta m_i)$$

In medical radiology 'matter' could for instance be a single organ or the whole body. The term 'energy imparted to matter' is much to be preferred from the point of view of clarity.

The special *unit of absorbed dose* is the rad (rd):

$$1\ \text{rd} = 0.01\ \text{J kg}^{-1} = 100\ \text{erg g}^{-1} = 2.388 \times 10^{-6}\ \text{cal}_{\text{IT}}\ \text{g}^{-1} = 6.242 \times 10^{13}\ \text{eV g}^{-1}$$

4.1.2 The *absorbed dose rate* $\dot{D}$ is the quotient of ΔD by Δt, where ΔD is the increment in absorbed dose in the time Δt:

$$\dot{D} = \frac{\Delta D}{\Delta t}$$

When the conditions are such that there is no variability in time $\dot{D} = D/t$.

Special *units of absorbed dose rate* are rad per second (rd s^{-1}), rad per minute (rd min^{-1}), rad per hour (rd h^{-1}), etc.:

$$1\ \text{rd s}^{-1} = 0.01\ \text{W kg}^{-1}$$

The direct measurement of absorbed dose or absorbed dose rate is possible only by means of calorimetry in phantoms and is very time-consuming. In practical dosimetry indirect methods are used, particularly those based on ionization measurements in air, in which the absorbed dose is obtained by simple calculation.

* The designation 'absorbed dose' has been criticized on the grounds that an 'absorbed dose' can be produced only in matter and not in vacuum. For this reason this quantity is known in the German literature as 'energy dose'.

(For references see page 221)

2 Exposure and exposure rate

4.2.1 The *exposure* (X) is the quotient of ΔQ by Δm, where ΔQ [illegible]

$$X = \frac{\Delta Q}{\Delta m}$$

The special *unit of exposure* is the roentgen** (R), defined as

1 R = 2.58×10^{-4} C kg^{-1} (exactly)

From the definition of the roentgen and the elementary charge $e \approx 1.602 \times 10^{-19}$ C it follows that an exposure of 1 R produces [illegible]

same methods as exposure and has the same numerical value when expressed in roentgen.

Secondary electron equilibrium exists at a point in matter when the sum of the kinetic energies of the photon-produced secondary electrons entering a volume containing this point is equal to the sum of the kinetic energies of the secondary electrons leaving this volume. This equilibrium can be established in an ionization chamber by enclosing the volume of air by a wall equivalent to air, for instance graphite, of a thickness at least equal to the range of the secondary electrons in this wall. A further condition is that the mean range of the photon-produced secondary electrons is small compared to $1/\mu$ (μ being the linear attenuation coefficient for the photons). Since this second condition is approximately fulfilled only for photons of energies up to about 3 MeV the equilibrium ion dose can be measured only when the photon energy is below this level. The introduction of the ionization chamber must not noticeably disturb the radiation field of the photons.

4.2.2 The *exposure rate* ($\dot{X}$) is the quotient of ΔX by Δt, where ΔX is the increment in exposure in time Δt:

$$\dot{X} = \frac{\Delta X}{\Delta t}$$

When the conditions are such that there is no variability in time $\dot{X} = X/t$

Special *units of exposure rate* are roentgen per second (R s^{-1}), roentgen per minute (R min^{-1}), roentgen per hour (R h^{-1}), etc.

1 R/s = 2.58×10^{-4} A kg^{-1}

Not included in the ICRU Reports[3] but appearing in the appropriate German DIN Standard[4] is the quantity 'ion dose', applicable to all kinds of radiation except neutrons.

4.2.3 The *ion dose* J produced by ionizing radiation in matter is the quotient of ΔQ by Δm_A, where ΔQ is the electric charge of the ions of one sign formed directly or indirectly by the radiation in air in a volume element ΔV, and Δm_A is the mass of the air of density ϱ_A in that volume element

$$J = \frac{\Delta Q}{\Delta m_A} = \frac{1}{\varrho_A} \cdot \frac{\Delta Q}{\Delta V}$$

The special *unit of ion dose* is likewise the roentgen (see above). From the definition of the roentgen and the elementary charge $e \approx 1.602 \times 10^{-19}$ C it follows that an ion dose of 1 R produces 1.610×10^{12} ion pairs per gramme (2.082×10^{9} ion pairs per cubic centimetre) of air at its normal density of 1.293 mg cm^{-3}.

4.2.4 The *ion dose rate* $\dot{J}$ is the quotient of ΔJ by Δt, where ΔJ is the increment in ion dose in time Δt

$$\dot{J} = \frac{\Delta J}{\Delta t}$$

When the conditions are such that there is no variability in time $\dot{J} = J/t$

The special *units of ion dose rate* are roentgen per second (R s^{-1}), roentgen per minute (R min^{-1}), roentgen per hour (R h^{-1}), etc.

** This unit is numerically identical with the old roentgen (r), defined as 1 electrostatic unit of charge per 1.293 mg of air

Table 2 Conversion of common units of exposure rate and ion dose rate

	mR h^{-1}	μR s^{-1}	R h^{-1}	R min^{-1}	R s^{-1}
1 mR h^{-1} =	1	2.8×10^{-1}	10^{-3}	1.7×10^{-5}	2.8×10^{-7}
1 μR s^{-1} =	3.6	1	3.6×10^{-3}	6×10^{-5}	10^{-6}
1 R h^{-1} =	10^{3}	2.8×10^{2}	1	1.7×10^{-2}	2.8×10^{-4}
1 R min^{-1} =	6×10^{4}	1.7×10^{4}	60	1	1.7×10^{-2}
1 R s^{-1} =	3.6×10^{6}	10^{6}	3.6×10^{3}	60	1

[illegible] instance air) the *Bragg-Gray conditions* are fulfilled when

(a) the flux density of the first generation of electrons and their energy distribution remain unchanged by the cavity filled with material B,

(b) the energy of the secondary electrons produced by the photons in material B is negligible in comparison with the energy imparted to material B,

(c) the flux density of the electrons of all generations within the material B is uniform throughout.

These conditions can be approximately met if the cavity contains air and its linear dimensions are small compared with $1/\mu$ (μ being the linear attenuation coefficient for the photons) and compared with the mean range of the secondary electrons. The walls of such a cavity ionization chamber must either be very thin or have values for mass energy transfer coefficient μ_K/ϱ and electron mass stopping power S_e/ϱ deviating only slightly from those of the surrounding material A in other words, the ionization of the air molecules in the cavity by the photons must be due predominantly to the secondary electrons produced in the surrounding material A. In order to reduce boundary layer effects between the material of the wall and the air in the cavity resulting from low-energy delta-electrons the inner side of the wall must be covered with a graphite layer about 1 μm thick. If this is not done the mean cavity ion dose will be dependent on the volume in which the dose is being measured

5. Conversion of dose quantities

5.1 The absorbed dose D_A for air is obtained from the ion dose J (measured as J_s* or J_c)

$$D_A = U_{iA} \cdot J$$

where $U_{iA} = 0.869$ rd/R is the ionization constant of air, obtained from the average energy E_i (= 33.7 eV) required for the formation of an ion pair in air, from the elementary charge e and from the relationship 1 V = 1 J/1 C = 2.58×10^{-4} rd R^{-1}. Above about 10 keV, U_{iA} remains practically constant over a wide energy range

5.2 For photon irradiation the absorbed dose D_Z at the point of interest in material Z is obtained from the absorbed dose D_A at the same point with secondary electron equilibrium in air (see paragraph 4.2.1.1 above) in accordance with the relationship

$$D_Z = D_A \cdot (\mu_K/\varrho)_Z/(\mu_K/\varrho)_A$$

where $(\mu_K/\varrho)_Z$ and $(\mu_K/\varrho)_A$ are the mass energy transfer coefficients (see paragraph 3.1, page 218) of the material Z (for instance body tissues) and air respectively for photons of energy E. For a photon spectrum the values $(\bar{\mu}_K/\varrho)_Z$ and $(\bar{\mu}_K/\varrho)_A$ averaged over the spectrum must be used instead.

For the *exposure* X** the conversion equations are as follows

(a) for photons of uniform energy E:

$$D_Z = f \cdot X, \text{ with } f = U_{iA} \cdot (\mu_K/\varrho)_Z/(\mu_K/\varrho)_A$$

(b) for a photon spectrum:

$$D_Z = \bar{f} \cdot X, \text{ with } \bar{f} = U_{iA} \cdot (\bar{\mu}_K/\varrho)_Z/(\bar{\mu}_K/\varrho)_A$$

Values of the conversion [illegible]

* Or exposure X (see paragraph 4.2.1.1).

** Or equilibrium ion dose J_s (see paragraph 4.2.1.1), in which case J_s must replace X in the formulae

sorbed dose D_A for air measured at the same point *under Bragg-Gray conditions* (see paragraph 4.2.5 above) in accordance with the relationship

$$D_Z = D_A \cdot (\bar{S}_e/\varrho)_Z/(\bar{S}_e/\varrho)_A$$

where $(\bar{S}_e/\varrho)_Z$ and $(\bar{S}_e/\varrho)_A$ are the electron mass stopping powers (see paragraph 3.2, page 218) of the material Z and of air averaged over the electron spectrum. Using the *cavity ion dose* J_c the conversion equation is as follows:

$$D_Z = \bar{g} \cdot J_c, \text{ with } \bar{g} = U_{iA} \cdot (\bar{S}_e/\varrho)_Z/(\bar{S}_e/\varrho)_A$$

Values of the conversion factor $\bar{g}$ for air, water and soft tissues are given in Table 5.

6. Relation of absorbed dose to radiation field

6.1 For photons of uniform energy the energy flux density ψ_{ph} of the photons at the point of interest is related to the absorbed dose rate $\dot{D}$ at the same point when there is secondary electron equilibrium as follows:

$$\dot{D} = (\mu_K/\varrho) \cdot \psi_{ph}$$

Similarly, for the absorbed dose D and the energy fluence Ψ_{ph} of the photons,

$$D = (\mu_K/\varrho) \cdot \Psi_{ph}$$

where μ_K/ϱ is the mass energy transfer coefficient of the material for photons of this energy.

6.2 For electrons of uniform energy the particle flux density φ_e of the electrons at the point of interest is related to the absorbed dose rate $\dot{D}$ at the same point under BRAGG-GRAY conditions as follows:

$$\dot{D} = (S_e/\varrho) \cdot \varphi_e$$

Table 3 Conversion factor $f = D/X$

E in MeV	f in rd R^{-1} for: Air	Water*	Soft tissues**	Bone (compact)**
0.010	0.869	0.912	0.925	3.54
0.015	0.869	0.890	0.916	3.97
0.020	0.869	0.877	0.916	4.23
0.030	0.869	0.870	0.910	4.39
0.04	0.869	0.873	0.919	4.14
0.05	0.869	0.893	0.926	3.58
0.06	0.869	0.915	0.929	2.91
0.08	0.869	0.937	0.939	1.91
0.10	0.869	0.942	0.948	1.45
0.15	0.869	0.964	0.956	1.05
0.20	0.869	0.971	0.963	0.979
0.30	0.869	0.964	0.957	0.938
0.4	0.869	0.967	0.954	0.928
0.5	0.869	0.964	0.957	0.925
0.6	0.869	0.964	0.957	0.925
0.8	0.869	0.967	0.956	0.920
1.0	0.869	0.967	0.956	0.922
1.5	0.869	0.966	0.958	0.920
2.0	0.869	0.966	0.954	0.921
3.0	0.869	0.964	0.954	0.928

* From National Bureau of Standards, Report 8681, U.S. Government Printing Office, Washington, 1965.
** From National Bureau of Standards, *Physical Aspects of Irradiation, ICRU Report 10b, 1962,* Handbook 85, U.S. Government Printing Office, Washington, 1964.

Table 5 Conversion factor $\bar{g} = D/J_c$

Radiation: Quantum energy or electron energy	Half-value layer or radionuclide	$\bar{g}$ in rd R^{-1} for: Air	Water	Soft tissues
(a) Bremsstrahlung at 400 kV tube potential	4.2 mm Cu	0.87	1.01	1.00
0.66 MeV	^{137}Cs	0.87	1.00	1.00
1.25 MeV	^{60}Co	0.87	0.99	0.99
Bremsstrahlung 15 MeV	–	0.87	0.98	0.97
Bremsstrahlung 30 MeV	–	0.87	0.95	0.94
Bremsstrahlung 45 MeV	–	0.87	0.94	0.93
(b) Electrons				
5 MeV	–	0.87	0.92	0.91
10 MeV	–	0.87	0.88	0.87
20 MeV	–	0.87	0.84	0.83
30 MeV	–	0.87	0.82	0.81
40 MeV	–	0.87	0.81	0.80
50 MeV	–	0.87	0.80	0.79

When calculating the absorbed dose for soft tissues embedded in bone the factor for the latter should be used since the effect of bone has already been allowed for in measurement of the cavity ion dose.
Values (a) from National Bureau of Standards, *Physical Aspects of Irradiation, ICRU Report 10b, 1962,* Handbook 85, U.S. Government Printing Office, Washington, 1964; (b) calculated from BERGER and SELTZER, *Tables of Energy Losses and Ranges of Electrons and Positrons,* NASA SP-3012, National Aeronautics and Space Administration, Washington, 1964, and *Additional Stopping Power and Range Tables for Protons, Mesons and Electrons,* NASA SP-3036, National Aeronautics and Space Administration, Washington, 1966.

Table 4 Conversion factor $\bar{f} = D/X$

Radiation: Tube potential in kV	Filter: mm Al	Filter: mm Cu	Half-value layer: mm Al	Half-value layer: mm Cu	$\bar{f}$ in rd R^{-1} for: Air	Water	Soft tissues	Bone (compact)
50	1.4	–	1.2	0.03	0.87	0.88	0.93	4.2
100	–	0.2	4.2	0.18	0.87	0.89	0.92	3.6
150	–	0.5	–	0.75	0.87	0.92	0.94	2.3
200	–	1.0	–	1.45	0.87	0.94	0.95	1.6
250	–	1.5	–	2.35	0.87	0.95	0.95	1.4
300	–	3.0	–	3.5	0.87	0.96	0.95	1.2
400	–	3.0	–	4.2	0.87	0.96	0.96	1.1

When calculating the absorbed dose for soft tissues embedded in bone from the measured exposure a value of $\bar{f}$ should be chosen lying between those for soft tissues and bone and depending on the distance of the bone from the point of measurement (cf. National Bureau of Standards, *Physical Aspects of Irradiation, ICRU Report 10b, 1962,* Handbook 85, U.S. Government Printing, Washington, 1964).

ularly, for the absorbed dose D and the particle fluence Φ_e of electrons,

$$D = (S_e/\varrho) \cdot \Phi_e$$

ere S_e/ϱ is the electron mass stopping power of the material for ctrons of this energy

Since the coefficients μ_K/ϱ and S_e/ϱ are themselves functions of

s an energy spectrum, in which case mean values of the coefficients over the spectral range must be used.

Relative biological effectiveness (RBE)

$$\xi = D_0/D$$

here D is the absorbed dose of the radiation under consideration that produces a particular biological effect, and D_0 the absorbed ose of a standard radiation (at present hard filtered 200 kV X rays) that produces the same effect under otherwise identical conditions The RBE factor is not a constant for a particular kind of radiation since different values are obtained depending on the nature of the radiation reaction being observed, on the kind of biological system under study, on the stage of development of the object being irradiated, and on the distribution of the absorbed dose in space and time[7] Since the RBE factor as such is unsuitable for use in the field of radiation protection the ICRU[3] has recommended that the term RBE should be employed in radiobiology only

Dose equivalent and quality factor[3, 4]

In radiation protection the place of the RBE factor ξ is taken by the quality factor* q, and that of the absorbed dose of the standard radiation – which is not used in radiation protection – by the dose equivalent* D_q, defined as follows

$$D_q = q \cdot D$$

The concept of dose equivalent is intended for use in radiation protection only The quality factor q is a dimensionless number whose magnitude depends mainly on the nature of the radiation, the particle energy and the conditions under which the irradiation takes place In practice, agreed conventional values of q are used based on the relative biological effectiveness ξ The dose equivalent is equal to the absorbed dose produced by a standard radiation with a quality factor $q = 1$ (at present 200 kV X rays), this absorbed dose is considered from the point of view of risk to be the same as the absorbed dose produced by the actual radiation with a quality factor $q \neq 1$

If a number of different radiations are present simultaneously the total dose equivalent is the sum of the dose equivalents of the individual radiations:

$$D_q = \sum_i D_{qi} = \sum_i (D_i q_i)$$

For dose equivalents the unit rad is given the special name rem (symbol rem):

$$1 \text{ rem} = 1 \text{ rd}$$

The term rem is reserved exclusively for expressing dose equivalents, so that data given in this unit are immediately recognizable as such

9. Specific gamma ray constant

The specific gamma ray constant Γ of a gamma-emitting radionuclide is the quotient of $l^2 \times \Delta\dot{X}$ by the activity A of the nuclide, where $\Delta\dot{X}$ is the exposure rate at a distance l from a point source of the nuclide and the gamma rays are assumed to undergo no absorption either in the sample or over the distance l.

$$\Gamma = \frac{\dot{X} \cdot l^2}{A}$$

$\dot{X}$ is normally only the exposure rate resulting from gamma radiation and from the annihilation radiation of positron-emitting nuclides If the X rays due to internal conversion or electron capture are not included this must be clearly stated when giving the specific

$$\Gamma_{Ra} = \frac{\dot{X} \cdot l^2}{m}, \text{ numerically } \Gamma_{Ra} = 0.825 \text{ R h}^{-1} \text{ m}^2 \text{ g}^{-1}$$

The special unit of specific gamma ray constant is

$$\frac{\text{roentgen} \times \text{square metre}}{\text{hour} \times \text{curie}} \quad (\text{R h}^{-1} \text{ m}^2 \text{ Ci}^{-1})$$

For ^{226}Ra the unit is

$$\frac{\text{roentgen} \times \text{square metre}}{\text{hour} \times \text{gramme}} \quad (\text{R h}^{-1} \text{ m}^2 \text{ g}^{-1})$$

If the activity A or the mass m_{Ra} of the radium is known the exposure rate at the distance l can therefore be calculated provided absorption of the gamma rays in the source and intervening air is neglected

$$\dot{X} = \Gamma \frac{A}{l^2} \quad \text{or} \quad \dot{X} = \Gamma_{Ra} \frac{m_{Ra}}{l^2}$$

* The symbol QF used in the ICRU Reports[3], like the symbol DE for dose equivalent, is inconvenient for use in formulae.

Table 6 Specific gamma ray constants of some radionuclides

Γ in R h^{-1} m^2 Ci^{-1}											
^{22}Na	^{24}Na	^{42}K	^{59}Fe	^{58}Co	^{60}Co	^{64}Cu	^{130}I	^{131}I	^{137}Cs + ^{137}Ba^m	^{192}Ir	^{198}Au
1.19	1.84	0.14	0.63	0.55	1.31	0.12	1.22	0.22	0.31	0.50	0.23

References

[1] Conférence Générale des Poids et Mesures, *Comptes rendus des séances de la 12e Conférence générale des Poids et Mesures*, Paris 1964, Gauthier Villars, Paris, 1964 page 94

[2] Quimby et al., *Radioactive Isotopes in Clinical Practice*, Lea & Febiger, Philadelphia 1958

ington, 1964

Quantity* and definition†	SI Unit Name	SI Unit Symbol
Electromagnetic radiation (radiant quantities)		
The **radiant energy** Q_e (or W) is the energy emitted, transferred or received as radiation.	joule	J
The **radiant energy density** w is the radiant energy in an element of volume divided by that element: $w = \mathrm{d}Q_e/\mathrm{d}V$.	joule per cubic metre	$\mathrm{J\,m^{-3}}$
The **radiant flux** or **radiant power** Φ_e is the power emitted, transferred or received as radiation: $\Phi_e = P = \mathrm{d}Q_e/\mathrm{d}t$.	watt	W
The **spectral concentration of radiant flux**** $\Phi_{e\lambda}$ is a spectral distribution function of radiant flux, i.e., the radiant flux in an infinitesimal wave-length interval divided by the range of that interval: $\Phi_e = \int \Phi_{e\lambda}\,\mathrm{d}\lambda$. $\Phi_{e\lambda}$ is often given in watt per nanometre ($1\ \mathrm{W\,nm^{-1}} = 10^9\ \mathrm{W\,m^{-1}}$).	watt per metre	$\mathrm{W\,m^{-1}}$
The **radiant intensity** I_e of a source in a given direction is the radiant flux leaving the source, propagated in an element of solid angle containing the given direction divided by that element of solid angle: $\Phi_e = \int I_e\,\mathrm{d}\Omega$.	watt per steradian	$\mathrm{W\,sr^{-1}}$
The **radiance** L_e at a point of a surface and in a given direction (ϑ = angle between the direction and the normal to the surface) is the radiant intensity of an element of the surface divided by the area of the orthogonal projection of that element on a plane perpendicular to the given direction: $\Phi_e = \int I_e\,\mathrm{d}\Omega = \iint L_e \cos\vartheta\,\mathrm{d}A\,\mathrm{d}\Omega$.	watt per steradian per square metre	$\mathrm{W\,sr^{-1}\,m^{-2}}$
The **radiant exitance** M_e at a point of a surface element is the radiant flux leaving an element of the surface divided by the area of that element: $\Phi_e = \int M_e\,\mathrm{d}A$.	watt per square metre	$\mathrm{W\,m^{-2}}$
The **irradiance** E_e at a point of a surface is the radiant flux incident on an element of the surface divided by the area of that element: $\Phi_e = \int E_e\,\mathrm{d}A$.	watt per square metre	$\mathrm{W\,m^{-2}}$
The **radiant exposure** H_e is the time integral of the irradiance: $H_e = \int E_e \mathrm{d}t$.	joule per square metre	$\mathrm{J\,m^{-2}}$
The (hemispherical) **emissivity** of a thermal radiator ε is the ratio of the radiant exitance of the radiator to that of a black body at the same temperature: $\varepsilon = M_e/M_{e,s}$***.	1	1
The **spectral** (hemispherical) **emissivity** of a thermal radiator $\varepsilon(\lambda)$ is the ratio of the spectral concentration of the radiant exitance of the radiator to that of a black body at the same temperature: $\varepsilon(\lambda) = M_{e\lambda}/M_{e\lambda,s}$†.	1	1
The **directional emissivity** of a thermal radiator $\varepsilon(\vartheta, \varphi)$ is the ratio of the radiance of the radiator in a given direction (ϑ, φ) to that of a black body at the same temperature: $\varepsilon(\vartheta, \varphi) = L_e/L_{e,s} = \int L_{e\lambda}\,\mathrm{d}\lambda / \int L_{e\lambda,s}\,\mathrm{d}\lambda$.	1	1
The **spectral directional emissivity** of a thermal radiator $\varepsilon(\lambda; \vartheta, \varphi)$ is the ratio of the spectral concentration of radiance in a given direction (ϑ, φ) of the radiator to that of a black body at the same temperature: $\varepsilon(\lambda; \vartheta, \varphi) = L_{e\lambda}/L_{e\lambda,s} < 1$.	1	1
Light (luminous quantities)		
The **luminous flux** Φ_v is the radiant flux evaluated photometrically, i.e., by its action on a selective receptor. The spectral function for evaluating the spectral concentration of radiant flux $\Phi_{e\lambda}$ is the spectral luminous efficacy $K(\lambda)$ or the spectral luminous efficiency $V(\lambda)$: $\Phi_v = \int K(\lambda)\,\Phi_{e\lambda}\,\mathrm{d}\lambda = K_{max} \int V(\lambda)\,\Phi_{e\lambda}\,\mathrm{d}\lambda$.	lumen	$\mathrm{lm = cd\,sr}$

* Where there is no risk of confusion between *radiant quantities* and the corresponding *luminous quantities* (i.e., the photometrically evaluated radiant quantities), or where the discussion concerns exclusively one of the two kinds of quantities, the subscripts of the symbols ('e' from 'energy', 'v' from 'visible') are omitted.

** Where there is no risk of confusion with the so-called 'spectral' quantities – for instance $\varepsilon(\lambda)$, $K(\lambda)$, $V(\lambda)$, $\varrho(\lambda)$, $\alpha(\lambda)$, $\tau(\lambda)$ – which though functions of wave length are nevertheless not spectral distribution functions in the sense of differential quotients with respect to wave length, the 'spectral concentration of a' quantity X (i.e., $X_\lambda = \mathrm{d}X/\mathrm{d}\lambda$) may be designated shortly the 'spectral' quantity X. Thus the 'spectral concentration of radiant flux' ($\Phi_{e\lambda}$) may be abbreviated to '*spectral radiant flux*'.

*** $M_{e,s}$ is the unpolarized radiant exitance of a black body at the temperature T: $M_{e,s} = \sigma T^4$ (for the STEFAN-BOLTZMANN constant $\sigma = \pi^2 k^4/60 \hbar^3 c^2$ see page 228).

† $M_{e\lambda,s}$ is PLANCK's expression for the unpolarized spectral concentration of radiant exitance of a black body at the temperature T: $M_{e\lambda,s} = c_1\lambda^{-5}\,[\exp(c_2/\lambda T) - 1]^{-1}$ (for the 1st and 2nd PLANCK radiation constants, $c_1 = 2\pi\,hc^2$ and $c_2 = hc/k$, see page 228).

Quantity* and definition†	SI Unit	
	Name	Symbol
Light (continued)		
[illegible]	lumen per metre	$lm\ m^{-1}$
[illegible]	lumen per watt	$lm\ W^{-1}$
The spectral luminous efficiency $V(\lambda)$ is the ratio of the spectral luminous efficacy (at a specified wave length λ) $K(\lambda)$ to the maximum spectral luminous efficacy K_{max}: $V(\lambda) = K(\lambda)/K_{max}$***	1	1
The quantity of light Q_v is the time integral of luminous flux. $Q_v = \int \Phi_v\, dt$. Q_v is often given in lumen hour (1 lm h = 3600 lm s)	lumen second	$lm\ s = cd\ sr$
The luminous intensity I_v of a light source in a given direction is the luminous flux leaving the light source, propagated in an element of solid angle containing the given [illegible] metre	candela	cd
[illegible]	candela per square metre	$cd\ m^{-2}$
The luminous exitance M_v†† at a point of a surface is the luminous flux leaving an element of the surface divided by the area of that element $\Phi_v = \int M_v\, dA$	lux	$lx = lm\ m^{-2} = cd\ sr\ m^{-2}$
The illuminance E_v at a point of a surface is the luminous flux incident on an element of the surface divided by the area of that element $\Phi_v = \int E_v\, dA$†††	lux	$lx = lm\ m^{-2} = cd\ sr\ m^{-2}$
The light exposure H_v is the time integral of illuminance $H_v = \int E_v\, dt$	lux second	$lx\ s = cd\ sr\ m^{-2}$
The luminous efficacy η_v of a light source is the luminous flux emitted, Φ_v, divided by the power consumed. $\eta_v = \Phi_v/P_{abs}$	lumen per watt	$lm\ W^{-1}$

* See footnote *, page 222

** See footnote **, page 222

*** The spectral luminous efficiency $V(\lambda)$ is at present given by the following internationally accepted values[2] [λ = numerical value of the wave length of light in nanometre (nm)]

λ	$V(\lambda)$	λ	$V(\lambda)$	λ	$V(\lambda)$	λ	$V(\lambda)$	λ	$V(\lambda)$	λ	$V(\lambda)$	λ	$V(\lambda)$	λ	$V(\lambda)$	λ	$V(\lambda)$	λ	$V(\lambda)$
400	0 000 4	440	0 023	480	0 139	520	0 710	555	1 000	590	0 757	630	0 265	670	0 032	710	0 0021	750	0 000 12
410	0 001 2	450	0 038	490	0 208	530	0 862	560	0 995	600	0 631	640	0 175	680	0 017	720	0 001 05	760	0 000 06
420	0 004 0	460	0 060	500	0 323	540	0 954	570	0 952	610	0 503	650	0 107	690	0 008 2	730	0 000 52		
430	0 011 6	470	0 091	510	0 503	550	0 995	580	0 870	620	0 381	660	0 061	700	0 004 1	740	0 000 25		

In order to distinguish them from the luminous quantities related to the spectral luminous efficiency for daylight vision $V(\lambda)$ (International Commission on Illumination, 1924), i e, those related to photopic vision (pure *cone* vision), the luminous quantities related to the spectral luminous efficiency for night vision $V'(\lambda)$ (International Commission on Illumination, 1951), i e, those related to scotopic vision (pure *rod* vision), are known as 'scotopic quantities'

† The unit candela per square centimetre (1 cd cm^{-2} = 10^4 cd m^{-2}) was formerly also known as the stilb (sb) [illegible]

is given by the relationship $\Phi_v = \int I_v\, d\Omega = \int M_v\, dA$ together with the definition of the candela, as follows

$$M_{v,s}(T_{Pt}) = K_{max} c_1 \int_0^\infty V(\lambda)\, \lambda^{-5} \{\exp(c_2/\lambda T_{Pt}) - 1\}^{-1}\, d\lambda = 6\pi \times 10^{5}\ lx$$

Quantity* and definition[1]	SI Unit	
	Name	Symbol
Light (concluded)		
The **spectral reflectance** $\varrho(\lambda)$ is the ratio of the spectral concentration of the reflected radiant (or luminous) flux to that of the incident radiant (or luminous) flux: $\varrho(\lambda) = \Phi_{\lambda r}/\Phi_{\lambda}$.	1	1
The **spectral absorptance** $\alpha(\lambda)$ is the ratio of the spectral concentration of the absorbed radiant (or luminous) flux to that of the incident radiant (or luminous) flux: $\alpha(\lambda) = \Phi_{\lambda a}/\Phi_{\lambda}$**.	1	1
The **spectral transmittance** $\tau(\lambda)$ is the ratio of the spectral concentration of the transmitted radiant (or luminous) flux to that of the incident radiant (or luminous) flux: $\tau(\lambda) = \Phi_{\lambda tr}/\Phi_{\lambda}$.	1	1
The **reflectance** ϱ, **absorptance** α and **transmittance** τ are the respective ratios of the reflected, absorbed and transmitted radiant (or luminous) flux Φ_r, Φ_a and Φ_{tr} to the incident radiant (or luminous) flux Φ. The following relationships hold for the quantities ϱ, α, τ and $\varrho(\lambda)$, $\alpha(\lambda)$, $\tau(\lambda)$: $\varrho = \int \Phi_\lambda\, \varrho(\lambda)\, d\lambda / \int \Phi_\lambda\, d\lambda = \Phi_r/\Phi$; $\alpha = \int \Phi_\lambda\, \alpha(\lambda)\, d\lambda / \int \Phi_\lambda\, d\lambda = \Phi_a/\Phi$; $\tau = \int \Phi_\lambda\, \tau(\lambda)\, d\lambda / \int \Phi_\lambda\, d\lambda = \Phi_{tr}/\Phi$; $\Phi = \Phi_r + \Phi_a + \Phi_{tr}$; $\varrho + \alpha + \tau = \varrho(\lambda) + \alpha(\lambda) + \tau(\lambda) = 1$	1	1

* See footnote *, page 222.

** For a thermal radiator emitting or absorbing in any direction (ϑ, φ): $\alpha(\lambda; \vartheta, \varphi) = \varepsilon(\lambda; \vartheta, \varphi) = L_{e\lambda}/L_{e\lambda,s} < 1$.

References

[1] International Electrotechnical Commission, *International Lighting Vocabulary*, Draft 3rd ed. and amendments, Geneva, 1966 (unpublished); International Organization for Standardization, *Quantities and Units of Light and Related Electromagnetic Radiations*, Draft ISO Recommendation No. 1778, January 1969 (unpublished).

[2] Comité International des Poids et Mesures, *Proc.-Verb. Com. int. Poids Mes.*, 15, 65 (1933).

[3] Comité International des Poids et Mesures, *Proc.-Verb. Com. int. Poids Mes.*, 20, 119 (1946), and 21, 67 (1948); Conférence Générale des Poids et Mesures, *Comptes rendus des séances de la 9e Conférence générale des Poids et Mesures*, Paris 1948, Gauthier-Villars, Paris, 1949, page 54; *Comptes rendus des séances de la 13e Conférence générale des Poids et Mesures*, Paris 1967/1968, Bureau International des Poids et Mesures, Sèvres, 1969, pages 71 and 104.

Quantity and definition[1]	Dimension	Units	
		SI unit	CGS unit
Acoustics†			
The **sound pressure** p is the alternating pressure due to an acoustical phenomenon and superimposed on the stationary atmospheric pressure. Values not otherwise specified are root mean square values, often called 'effective' values.	$L^{-1}\,M\,T^{-2}$	$N\,m^{-2}$	$dyn\,cm^{-2}$ ($= \mu bar$)
The **sound particle velocity** v is the instantaneous velocity of a particle of the medium set in motion by an acoustical phenomenon. Values not otherwise specified are root mean square values, often called 'effective' values.	$L\,T^{-1}$	$m\,s^{-1}$	$cm\,s^{-1}$
The **sound pressure level** L_p is defined[1] as 20 $\log_{10}(p/p_0)$ in decibel (dB), where p is the root mean square value of the measured sound pressure, and p_0 is the root mean square value of a reference pressure. For air: $p_0 = 2 \times 10^{-5}\ N\,m^{-2} = 2 \times 10^{-4}\ \mu bar$ is generally used[1].	$L^0\,M^0\,T^0$	dB††	dB††
The **sound energy** W is the mechanical energy radiated as sound.	$L^2\,M\,T^{-2}$	W s	erg
The **sound power** or **sound energy flux** P is the sound energy transferred in a certain time interval divided by the duration of that interval: $P = dW/dt$.	$L^2\,M\,T^{-3}$	W	$erg\,s^{-1}$

† This section (pages 224–226) has been compiled in collaboration with W. Furrer, Zurich.

†† The decibel is not a unit of either the SI or the CGS system.

Quantity and definition[1]	Dimension	Units	
		SI unit	CGS unit
Acoustics (continued)			
The sound intensity I for unidirectional sound energy flux is the sound energy flux through an area normal to the direction of propagation divided by that area $P = \int I dA$.	M T^{-3}	W m^{-2}	erg s^{-1} cm^{-2}
The velocity of sound c is the velocity of propagation of a sound wave. It is a constant depending on the medium and independent of the frequency or intensity of the sound wave. The velocity of sound in air depends mainly on the temperature and is given by $c_{air} = (331.4 + 0.607\,t)$ m s^{-1}, where t is the numerical value of the temperature in degree Celsius. Note At very high intensities (explosions) the velocity of sound may be higher.	L T^{-1}	m s^{-1}	cm s^{-1}

Quantity and definition	Dimension	SI unit
The periodic time or period T is the time taken by a periodic phenomenon in an arbitrarily defined state to return for the first time to that state	T	s
The frequency ν (or f) of a periodic phenomenon is the reciprocal of its periodic time. In acoustical phenomena the subjective impression of the pitch depends on the frequency. *Standard musical pitch* is the frequency for the note A in the treble stave, defined as 440 Hz[2].	T^{-1}	Hz
The loudness level L_N (or Λ) of a sound or noise is expressed on the dimensionless phon scale[1]. The loudness level amounts to n phon when it is judged by a normal observer under standardized listening conditions to be as loud as a pure tone of frequency 1000 Hz consisting of a plane progressive sound wave, coming from directly in front of the observer, the sound pressure level of which is $L_p = n$ dB (see above), i.e., $L_N = 20 \log_{10}(p/p_0)_{1\,kHz}$. In principle, therefore, loudness levels can be measured in phon only by a subjective hearing test, objective tests yield only more or less exact approximations.	L^0 M^0 T^0	phon*
Loudness N (or S) Owing to the arbitrary definition of the decibel and phon scales, loudness levels on these scales do not immediately correspond to the sensation of loudness but have to be interpreted by the user on the basis of his personal experience of sounds of known phon value The sone scale provides a means of expressing the subjective sensation of loudness and is defined[1] by the following relationship between loudness N in sone and loudness level L_N in phon	L^0 M^0 T^0	sone*

$$N = 2^{0.1(L_N - 40)} \text{ or } \log_{10} N = 0.1(L_N - 40) \log_{10} 2 \approx 0.03\,(L_N - 40)$$

Corresponding values of L_N and N calculated from this 'loudness function' are as follows

L_N in phon	N in sone	L_N in phon	N in sone	L_N in phon	N in sone
20	0.25	55	2 83	90	32 0
25	0 35	60	4 00	95	45 3
30	0 50	65	5 66	100	64 0
35	0 70	70	8 00	105	90 5
40	1 00	75	11 3	110	128
45	1 41	80	16 0	115	181
50	2 00	85	22 6	120	256

It should be noted that
1 Loudness in sone cannot be measured directly but must be calculated from the loudness level in phon.
2. A loudness of 1 sone corresponds to a loudness level of 40 phon
3 A twofold change in loudness corresponds to a loudness level difference of 10 phon
4 The relationship has been confirmed experimentally only between 20 and 120 phon, outside this range its use must be regarded as an extrapolation

* Not an SI unit

Calculation of loudness levels

Loudness levels can also be calculated from noise analyses, the two best-known methods being those of Stevens[3] and Zwicker[4]. The [illegible]

[illegible]

it by a particular method

A modification of Stevens' method has been introduced for the measurement of aircraft noise[5]. The values so obtained are known as 'perceived noise levels' (PN) and are expressed in decibel. Th[ey] represent a degree of correlation of objective measurements w[ith] subjective sensation not attainable simply by measuring sound pr[es]sure levels

Sound level meters

In view of the complexity of the human ear and the diffic[ult] nature of the subjective hearing tests required for the measureme[nt] of loudness levels in phon, sound level meters measuring cert[ain] weighted sound pressure levels have been standardized[6] T[he] weighting applied to each sinusoidal component of the sound pr[essure]

sure is given as a function of frequency by *three standard reference curves* A, B and C. The varying sensitivity of the ear is taken into account by using curve A for low sound pressure levels, curve B for moderate sound pressure levels, and curve C for high sound pressure levels. In each measurement the curve used must be shown, for instance by placing the appropriate letter after the decibel value: 45 dB(A), 95 dB(C). The 'DIN-phon' earlier used in Germany[7] was based on the same principle.

More recent measurements of the frequency response of the ear[8] and studies of the correlation between sound pressure level and loudness level measurements have shown that the use of the curve A gives best agreement with the subjective sensation and that this applies not only to low but also to high sound pressure levels. This is being taken into account by the ISO when standardizing in this field, with the result that the tendency is now for sound levels to be measured and given in dB(A). Sound pressure levels in dB(A) should also be given when loudness levels are measured or calculated in any form (for instance L_N in phon or in phon by STEVENS' method, PN in dB, etc.).

Typical sound levels

The following examples from everyday life illustrate the range of the dB(A) sound level scale:

Source	Sound level in dB(A)
Propeller aircraft at 5 m	130
Pneumatic hammer at 1 m	120
Brass foundry	110
Motor-car horn at 5 m	100
Truck at 5 m	90
Loud radio music	80
Normal conversation at 1 m	70
Motor car at 10 m	60
Quiet stream or river	50
Residential district without traffic	40
Quiet garden	30
Ticking of a watch	20
Limit of audible noise	10
Absolute silence	0

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Amount of substance

Amount of substance (n) and amount of equivalent (n_{aeq})

Dimension = N
(Additional*) base unit = mole (mol)

Except in special cases, there is no practicable method of counting the numbers of particles involved in a chemical or physical process. For this reason the IUPAP[1,6] in 1957 introduced the basic quantity *amount of substance n* for use in chemical and molecular physics. The concept of amount of substance is founded on the 'countability' of identical individuals (particles) in an atomic or other discontinuous system[2]. The value of n *is proportional to the number of particles* N, the proportionality factor being a fundamental constant, the AVOGADRO constant (see also page 228) $N_A = N/n$ (dimension = N^{-1}). The number of particles in a population having the amount of substance n = 1 mol is therefore $N = N_A \times 1$ mol = 6.0222×10^{23}.

The *base unit of amount of substance* is the *mole** (mol). The primary standard for the mole – as well as for the scale of relative atomic masses A_r and the (unified) atomic mass unit (u) – is the carbon nuclide ^{12}C on which the IUPAC and IUPAP agreed in 1960–61[3,4]. *As defined by the IUPAC*[6], **, *the mole is the amount of substance of a system which contains as many elementary units as there are carbon atoms in 0.012 kg of the pure nuclide carbon-12* (^{12}C). The elementary unit *must be specified* and may be an atom, a molecule, an ion, an electron, a photon, etc., or a *specified* group of such entities.

The concept of amount of substance may be extended to FARADAY's *law of equivalence* and *chemical bonds*. Here use is made of the *amount of equivalent* n_{aeq} (dimension likewise N): $n_{aeq} = z\,n$, where z is the charge number in the case of ions and the number (single, double, etc.) in the case of bonds. The amount of equivalent n_{aeq} is proportional to the electric charge $Q = N z e$ (e = elementary charge; see also page 228) of N ions of charge number z, the proportionality factor again being a fundamental constant, the FARADAY constant F (see also page 228) $= Q/n_{aeq} = e\,N/n = e\,N_A$ (dimension = TIN^{-1}). The *unit of amount of equivalent* is likewise the base unit mole*. The electric charge carried by the amount of equivalent $n_{aeq} = z\,n$ = 1 mole of a particular species of ion is therefore $Q = F\,n_{aeq} = F \times 1$ mol $= 9.6487 \times 10^4$ C.

Scale of relative atomic masses (A_r) and the (unified) atomic mass unit (u)

The unified scale of relative atomic masses A_r, with ^{12}C as reference nuclide or primary standard, is defined[3,4] by the assigned value

$$A_r(^{12}C) = 12$$

Using the mass $m(^{12}C)$ of an atom of the nuclide ^{12}C as primary standard, the (unified) atomic mass unit (u) is defined by the relation[3]

$$1\ u = m(^{12}C)/12$$

The atomic mass of any nuclide X can therefore be written as $m(X) = A_r(X)$ u with

$$1\ u = 10^{-3}\ (N_A\ \text{mol})^{-1}\ \text{kg} = 1.66053 \times 10^{-27}\ \text{kg}$$

Tables of the relative atomic masses $m(X)$ of the nuclides have been published at the instance of the Commission on Atomic Masses and Related Atomic Constants of the IUPAP[9,10]. These data, together with the 'natural' or 'average' relative abundancies of the stable isotopes of the elements, have formed since 1961 the basis of the tables of 'atomic weights' of the elements issued by the *Commission on Atomic Weights of the IUPAC*[11].

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* Previously the mole, defined as 1 mol = M_r g (M_r = relative molecular mass, or 'molecular weight', of the substance concerned), has been used as an individual (chemical) mass unit[2]. Linked to the mole there is a *further individual (electrochemical) mass unit for ions of a chemically homogeneous* substance, the gramme-equivalent Eq, defined by 1 Eq = $(1/z)$ mol = (M_r/z) g (the symbol val is also used in place of Eq). The ratio M_r/z is known as the equivalent weight of the ions. These units have now been superseded by the dimensionless quantity *amount of equivalent* ($n_{aeq} = z n$), i.e., the terms amount of equivalent $n_{aeq} = y$ mol and amount of substance $n = (y/z)$ mol of the ions in the new formulation replace the earlier statement of a 'mass y Eq of ions of molecular weight M_r and electrovalency z'.

At the instigation of the IUPAC, IUPAP and ISO, the Advisory Committee on Units in 1967 recommended[8] to the International Committee of Weights and Measures that the International System of Units should be extended to include a seventh base unit, the mole, as base unit of amount of substance. The 13th General Conference of Weights and Measures in 1967 deferred a decision on this proposal. This recommendation was confirmed[8a] by the Advisory Committee on Units in 1969.

Editors' note: In view of the fact that in clinical chemistry the equivalent, milliequivalent, etc., continue for the time being to be used as mass units for ions, the editors have refrained from making corresponding changes in the data given in subsequent chapters of these *Scientific Tables*.

** The same definition of the mole has been agreed upon by the ISO[7] and IUPAP[5], except that the latter has chosen a slightly different wording.

...ortant quantities representing concentration

Quantity*	Symbol and definition	mol-SI units**
Molecular concentration of the component i (L^{-3})	$C_i = N_i/V$ (in a mixture of volume V)	m^{-3}
Mass concentration of the component i (L^{-3} M)	$\varrho_i = \bar{m}_i/V$ (in a mixture of volume V) ($\bar{m}_i$ = mass of component i)	kg m^{-3}
Molarity of the component i (L^{-3} N)	$c_i = n_i/V$ (amount of substance in mol related to the volume of the mixture or solution)***	mol m^{-3}
Molality of the solute substance i (M^{-1} N)	$m_i = n_i/\bar{m}_0$ (amount of substance in mol related to the mass $\bar{m}_0$ of the solvent)***	mol kg^{-1}
Equivalent concentration of the ion i (L^{-3} N)	$c_{\mathrm{eq},i} = z_i c_i = z_i n_i/V$ (in a solution of volume V)***	mol m^{-3}
Ionic strength of a solution (M^{-1} N)	$I = \frac{1}{2}\sum_i z_i^2 m_i = \frac{1}{2}\sum_i z_i^2 n_i/\bar{m}_0$ ($\bar{m}_0$ = mass of solvent)	mol kg^{-1}

* Dimensions in brackets
** Coherent unit in the International System of Units supplemented by the base unit mole (see above and reference[8])

*** A solution of molarity $c_i = y$ mol/l is known as 'y-molar' with respect to the component i, a solution of molality $m_i = y$ mol/kg as 'y-molal' with respect to the component i, a solution of equivalent concentration $c_{\mathrm{eq},i} = y$ mol/l as 'y-normal' with respect to the ions of species i

...uantities related to amount of substance

Apart from amount of substance n, a number of other quantities [illegible]

...m and R (L^2 M T^{-2} Θ^{-1} N^{-1})

In analogy with the quantities related to amount of substance the ...quivalent conductivity Λ (L^{-3} M^{-1} T^3 I^2 N^{-1}) has, for instance, been ...ntroduced as the conductivity γ related to the equivalent concen...tration $c_{\mathrm{eq}} = n_{\mathrm{eq}}/V$ (V = volume of the solution) $\Lambda = \gamma/c_{\mathrm{eq}}$.

Earlier 'physical' (A_{ph}) and 'chemical' (A_{ch}) scales of atomic weights

Before agreement was reached on the unified ^{12}C scale, different relative mass scales[2] were in use in physics and chemistry[2], namely the 'physical scale of atomic weights' based on the oxygen nuclide ^{16}O as primary standard and defined by $A_{\mathrm{ph}}(^{16}O) = 16$, and the 'chemical scale of atomic weights' based on elementary oxygen, i.e., on the 'naturally' [illegible]

[illegible] scale of relative atomic masses [$A_r(^{12}C) = 12$], and between the three corresponding units of amount of substance mol ($^{16}O = 16$), mol ($\bar{O} = 16$) and mol($^{12}C = 12$)

$$\frac{A_r(^{16}O = 16)}{A_r(^{12}C = 12)} = \frac{\mathrm{mol}(^{16}O = 16)}{\mathrm{mol}(^{12}C = 12)} = 1.00031791^{10}$$

($3s = \pm 5 \times 10^{-8}$)

$$\frac{A_r(\bar{O} = 16)}{A_r(^{12}C = 12)} = \frac{\mathrm{mol}(\bar{O} = 16)}{\mathrm{mol}(^{12}C = 12)} = \frac{1.000318}{k_A} = 1.000043$$

($3s = \pm 15 \times 10^{-6}$)

Former atomic mass unit (amu)

The former atomic mass unit (amu), based on the oxygen nuclide ^{16}O as primary standard and linked to the physical scale of atomic weights, was defined through the mass $m(^{16}O)$ of an atom of the nuclide ^{16}O

$$1\ \mathrm{amu} = m(^{16}O)/16$$

The atomic mass of any nuclide X was therefore written as $m(X) = A_{\mathrm{ph}}(X)$ amu. The relationship between the earlier and the present unified atomic mass unit is given by

$$1\ \mathrm{u} = \frac{A_r(^{16}O = 16)}{A_r(^{12}C = 12)}\ \mathrm{amu}$$

R...

[7] [illegible] (unpublished)

[8] Comité consultatif des unités, 1re session, Paris, 1967, p...

[8a] Comité consultatif des unités, 2e session, Paris 1969 (in pre...

[9] Everling et al., *Nuclear Phys.*, 18, 529 (1960), König et al. ... *...ear Phys.*, 31, 18 (1962)

[12] International Union of Pure and Applied Chemistry, *Comptes rendus de la 17e conférence*, Stockholm 1953, Butterworth, London, page 93, *Comptes rendus de la 18e conférence*, Zurich 1955, Butterworth, London, page 115

Physical Constants†

	Symbol and formula	Numerical value	CGS system	International System of Units	Noncoherent units
Gravitational constant†	G	6.670 ± 0.015	10^{-8} dyn cm^2 g^{-2}	10^{-11} N m^2 kg^{-2}	
Electromagnetic field constants (see also page 215)					
Velocity of light in vacuum†	c $1/c$ c^2 $1/c^2$	2.997 925 3.335 640 5 8.987 554 3 1.112 649 7	10^{10} cm s^{-1} 10^{-11} cm^{-1} s 10^{20} cm^2 s^{-2} 10^{-21} cm^{-2} s^2	10^{8} m s^{-1} 10^{-9} m^{-1} s 10^{16} m^2 s^{-2} 10^{-17} m^{-2} s^2	
Magnetic field constant.............	$\mu_0 = 4\pi\, 10^{-7}$ Hm^{-1}	1.256 637 061		10^{-6} H m^{-1}	
Electric field constant	$\varepsilon_0 = 1/\mu_0 c^2$	8.854 185 3		10^{-12} F m^{-1}	
Impedance of vacuum..............	$\Gamma_0 = \mu_0 c$	3.767 303 7		$10^2\ \Omega$	
Thermodynamic constants†–4					
Molar volume of an ideal gas under standard conditions..............	V_{m0}	2.241 36	10^4 cm^3 mol^{-1}	10^{-2} m^3 mol^{-1}	
Molar gas constant	$R = p_0\, V_{m0}/T_0$	8.314 3 8.205 6 1.987 2 1.986 5 1.985 8	10^7 erg K^{-1} mol^{-1}	J K^{-1} mol^{-1}	 10 cm^3 atm K^{-1} mol^{-1} cal$_{th}$ K^{-1} mol^{-1} § cal$_{15}$ K^{-1} mol^{-1} cal$_{IT}$ K^{-1} mol^{-1}
Atomic constants†–4					
Avogadro constant††	N_A	6.022 2	10^{23} mol^{-1}	10^{23} mol^{-1}	
Loschmidt constant†††	$n_L = N_A/V_{m0}$	2.686 8	10^{19} cm^{-3}	10^{25} m^{-3}	
Boltzmann entropy constant	$k = R/N_A$	1.380 6 1.362 6 8.617 1 3.299 8 3.298 6 3.297 6	10^{-16} erg K^{-1}	10^{-23} J K^{-1}	 10^{-22} cm^3 atm K^{-1} 10^{-5} eV K^{-1} 10^{-24} cal$_{th}$ K^{-1} § 10^{-24} cal$_{15}$ K^{-1} 10^{-24} cal$_{IT}$ K^{-1}
Elementary charge.................	e e^* e^*/c	1.602 2 4.803 2 1.602 2	 10^{-10} esu 10^{-20} emu	10^{-19} C	
Faraday constant	$F = N_A e$ $F^* = N_A e^*$ $F^*/c = N_A e^*/c$	9.648 7 2.892 6 9.648 7	 10^{14} esu mol^{-1} 10^{3} emu mol^{-1}	10^4 C mol^{-1}	
Sommerfeld fine-structure constant..	α $1/\alpha$ α^2	7.297 35 1.370 36 5.325 1	10^{-3} 10^2 10^{-5}	10^{-3} 10^2 10^{-5}	
Planck constant (quantum of action).	$h = 2\pi (e^*)^2/\alpha c$ h/e^* $h c/e^*$ h/e	6.626 2 1.379 52 }4.135 71	10^{-27} erg s 10^{-17} erg s esu^{-1} 10^{-7} erg s emu^{-1}	10^{-34} J s 10^{-15} J s C^{-1}	
Quantum-mechanical unit of angular momentum.....................	$\hbar = h/2\pi$	1.054 59	10^{-27} erg s	10^{-34} J s	
1st Planck radiation constant.......	$c_1 = 2\pi h c^2$ $h c^2$	3.741 8 5.955 3	10^{-5} erg cm^2 s^{-1} 10^{-6} erg cm^2 s^{-1}	10^{-16} W m^2 10^{-17} W m^2	
2nd Planck radiation constant	$c_2 = h c/k$ $c_2/c = h/k$	1.438 8 4.799 4	cm K 10^{-11} s K	10^{-2} m K 10^{-11} s K	
Constant of Wien's displacement law.	$b = \lambda_{max}\, T = c_2/x$; $x = 4.965\,114\,23$	2.897 9	10^{-1} cm K	10^{-3} m K	
Stefan-Boltzmann constant........	$\sigma = \pi^2 k^4/60 \hbar^3 c^2$	5.669 6	10^{-5} erg cm^{-2} s^{-1} K^{-4}	10^{-8} W m^{-2} K^{-4}	
Bohr radius (of the first-quantized electron orbit of the hydrogen atom)..	$a_0 = \alpha/4\pi R_\infty$	5.291 77	10^{-9} cm	10^{-11} m	

† The data on the physical constants (pages 228 and 229) have been compiled in collaboration with E.R. Cohen, North American Aviation Science Center, Thousand Oaks, Calif., USA. The values given are corrected from a consistent set derived by the Committee on Fundamental Constants of the National Academy of Sciences – National Research Council (USA)[1,2]. The original set was approved by the International Union of Pure and Applied Physics at the 12th General Assembly in 1963[3] and published in 1965[4]. The numerical values given here correct these data to reflect a change of 20 ppm in the value of the Sommerfeld fine-structure constant. This change has been made necessary by recent measurements of the macroscopic quan- ... in superconductors and on the fine structure in the

The quantities elementary charge, Faraday constant, gyromagnetic ratio and magnetic moment, defined non-rationally in the symmetrical three-dimensional system of quantities, are given the symbols e^*, F^*, γ^* and μ^*, the corresponding quantities defined rationally in the four-dimensional system have the symbols e, F, γ and μ: $e^*/e = F^*/F = (4\pi\varepsilon_0)^{-1/2}$, $\gamma^*/\gamma = \mu^*/\mu = (\mu_0/4\pi)^{1/2}$ (see 'Electricity and Magnetism', page 215).

†† The molar number of molecules (see 'Quantities related to amount of substance', page 227). Formerly known as the *Loschmidt constant* in German-speaking countries.

††† The number density of molecules of an ideal gas at 0 °C and 760 torr. Formerly known as the Avogadro constant in German-speaking countries

	Symbol and formula	Numerical value	CGS system	International System of Units	Noncoherent units
Atomic constants (continued)					
Electron radius	$r_e = \alpha^2/4\pi R_\infty$	2 817 94	10^{-13} cm	10^{-15} m	
THOMSON cross-section	$(8\pi/3) r_e^2$	6 652 5	10^{-25} cm^2	10^{-29} m^2	10^{-1} barn
COMPTON wave length					
of electron	$\lambda_{C,e} = h/m_e c$	2 426 31	10^{-10} cm	10^{-12} m	
	$\lambda_{C,e}/2\pi$	3 861 59	10^{-11} cm	10^{-13} m	
of proton	$\lambda_{C,p} = h/m_p c$	1 321 44	10^{-13} cm	10^{-15} m	
	$\lambda_{C,p}/2\pi$	2 103 14	10^{-14} cm	10^{-16} m	
of neutron	$\lambda_{C,n} = h/m_n c$	1 319 62	10^{-13} cm	10^{-15} m	
	$\lambda_{C,n}/2\pi$	2 100 24	10^{-14} cm	10^{-16} m	
RYDBERG constant					
for an atom with a nucleus of infinite mass	R_∞	1 097 373 1	10^5 cm^{-1}	10^7 m^{-1}	
for ^{1}H atom	$R_H = R_\infty/(1+m_e/m_p)$	1 096 775 8	10^5 cm^{-1}	10^{-7} m^{-1}	
RYDBERG frequency					
for an atom with a nucleus of infinite mass	$R'_\infty = R_\infty c$	3 289 842	10^{15} s^{-1}	10^{15} s^{-1}	
for ^{1}H atom	$R'_H = R_H c$	3 288 052	10^{15} s^{-1}	10^{15} s^{-1}	
Charge to mass ratio for positron	e/m_e	1 758 80		10^{11} C kg^{-1}	
	e^*/m_e	5 272 76	10^{17} esu g^{-1}		
	$e^*/c\,m_e$	1 758 80	10^7 emu g^{-1}		
Charge to mass ratio for proton	e/m_p	9 579 00		10^7 C kg^{-1}	
	e^*/m_p	2 871 72	10^{14} esu g^{-1}		
	$e^*/m_p c$	9 579 00	10^3 emu g^{-1}		
Gyromagnetic ratio of proton	γ_p^*	2 675 19	10^4 s^{-1} emu^{-1}		
	γ_p			10^8 s^{-1} T^{-1}	
Effective gyromagnetic ratio of proton in a spherical sample of water (uncorrected for diamagnetism in water sample)	$\gamma_p^{*\prime}$	2 675 13	10^4 s^{-1} emu^{-1}		
	γ'_p			10^8 s^{-1} T^{-1}	
BOHR magneton	$\mu_B^* = h e^*/2 m_e c$	9 274 1	10^{-21} erg emu^{-1}		
	$\mu_B = h e/2 m_e$			10^{-24} J T^{-1}	
Nuclear magneton	$\mu_N^* = (m_e/m_p)\mu_B^*$	5 051 0	10^{-24} erg emu^{-1}		
	$\mu_N = (m_e/m_p)\mu_B$			10^{-27} J T^{-1}	
Magnetic moment of electron	$\mu_e^* = \mu_B^*(\mu_e^*/\mu_B^*)$	9 284 9	10^{-21} erg emu^{-1}		
	$\mu_e = \mu_B(\mu_e/\mu_B)$			10^{-24} J T^{-1}	
	$\mu_e^*/\mu_B^* = \mu_e/\mu_B = 1 + \alpha/2\pi - 0.328\alpha^2/\pi^2$	1 001 159 64			
Magnetic moment of proton	$\mu_p^* = \gamma_p^* h/2$	1 410 6	10^{-23} erg emu^{-1}		
	$\mu_p = \gamma_p h/2$			10^{-26} J T^{-1}	
	$\mu_p^*/\mu_B^* = \mu_p/\mu_B$	1 521 033	10^{-3}	10^{-3}	
	$\mu_p^*/\mu_N^* = \mu_p/\mu_N$	2 792 78			
Effective magnetic moment of proton in a spherical sample of water	$\mu_p^{*\prime}/\mu_N^* = \mu'_p/\mu_N$	2 792 71			
ZEEMAN splitting constant	$e^*/4\pi m c^2$	4 668 6	10^{-5} cm^{-1} emu^{-1}		
	$e/4\pi m c$			10 m^{-1} T^{-1}	
Atomic mass constant	$m_u = (1/N_A)$ g mol^{-1}	1 660 53	10^{-24} g	10^{-27} kg	
	$= m(^{12}C)/12$	1			u
Rest mass of electron †	$m_e = 4\pi(e^*)^2 R_\infty/\alpha^2 c^2$	9 109 6	10^{-28} g	10^{-31} kg	
	$= e^2 R_\infty/\varepsilon_0 \alpha^3 c^2$	5 485 93			10^{-4} u
Rest mass of proton †	$m_p = m(^1H) - m_e$	1 672 62	10^{-24} g	10^{-27} kg	
		1 007 276 61			u
Ratio of the rest masses of proton and electron	m_p/m_e	1 836 1	10^3	10^3	
Rest mass of neutron †	$m_n = A_{rn} m_u$	1 674 92	10^{-24} g	10^{-27} kg	
		1 008 665 20			u
Rest mass of ^{1}H atom †	$m(^1H) = A_r(^1H) m_u$	1 673 52	10^{-24} g	10^{-27} kg	
		1 007 825 2			u
Reduced mass of electron in ^{1}H atom	$\mu = m_e m_p/m(^1H)$	9 104 6	10^{-28} g	10^{-31} kg	
		5 482 94			10^{-4} u
Energy equivalents ††					
Atomic mass unit	$E(u) = c^2 \times (1\,u)$	1 492 411	10^{-3} erg	10^{-10} J	
		9 314 81			10^8 eV
Electron mass	$E(m_e) = c^2 m_e$	8 187 26	10^{-7} erg	10^{-14} J	
		5 110 04			10^5 eV
Proton mass	$E(m_p) = c^2 m_p$	1 503 27	10^{-3} erg	10^{-10} J	
		9 382 60			10^8 eV
Neutron mass	$E(m_n) = c^2 m_n$	1 505 34	10^{-3} erg	10^{-10} J	
		9 395 53			10^8 eV

† Relative atomic masses (A_r) (formerly 'atomic weights') of electron, proton, neutron and ^{1}H atom = numerical value × power of ten of the appropriate rest mass measured in the atomic mass unit u (dimensionless)

†† For other energy equivalents see page 213

References

[1] National Academy of Sciences – National Research Council Committee, *Nat Bur Stand*, *Techn News Bull*, 47, 175 (1963)

[2] Cohen

Standard substances

Mercury

Density under standard conditions[1] (0 °C, 760 torr):
$\varrho_n(Hg) = 13.595\,08$ kg dm^{-3}

The mean density of pure mercury at the temperature t_{68} in a barometric column supported by the pressure p being measured is given, with sufficient accuracy over the temperature range from 0 °C to 40 °C and for the pressures relevant to the IPTS-68 (see page 209), by the relation[2]

$$\varrho\left(t_{68}, \frac{p}{2}\right) = \frac{\varrho\,(20\,°C, p_0)}{[1 + A(t_{68} - 20\,°C) + B(t_{68} - 20\,°C)^2] \cdot [1 - \varkappa\,(\frac{p}{2} - p_0)]}$$

where $A = 18\,115 \times 10^{-8}\,°C^{-1}$; $B = 0.8 \times 10^{-8}\,°C^{-2}$; compressibility $\varkappa = 4 \times 10^{-11}$ N^{-1} m^2; $\varrho\,(20\,°C, p_0) = 13\,545.87$ kg/m^3.

Relative density with density of water as reference quantity ('specific gravity'):
$d(Hg) = \varrho_n(Hg)/\varrho_{max}(H_2O) = 13.595\,46$

Water

Maximum density[3] ($\approx$ 3.98 °C, 760 torr, air-free):
$\varrho_{max}(H_2O) = (0.999\,972 \pm 0.000\,003)$ kg dm^{-3}

Density between 0 and 40 °C in kg dm^{-3} (760 torr, air-saturated)[4]

°C		°C		°C		°C		°C	
0	0.999 840	3	0.999 964	6	0.999 940	9	0.999 781	12	0.999 498
1	0.999 899	4	0.999 972	7	0.999 902	10	0.999 700	13	0.999 378
2	0.999 940	5	0.999 964	8	0.999 849	11	0.999 606	14	0.999 245

°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
15	0.999 101	085	070	055	039	024	008	*992*	*976*	*960*
16	0.998 944	928	911	895	878	862	845	828	811	793
17	0.998 776	759	741	724	706	688	670	652	634	615
18	0.998 597	578	560	541	522	503	484	465	446	426
19	0.998 407	387	367	347	328	308	287	267	247	226
20	0.998 206	185	164	143	122	101	080	059	037	016
21	0.997 994	972	951	929	907	885	862	840	818	795
22	0.997 772	750	727	704	681	658	634	611	588	564
23	0.997 540	517	493	469	445	421	397	372	348	323
24	0.997 299	274	249	224	199	174	149	124	098	073
25	0.997 048	021	*996*	*970*	*944*	*918*	*892*	*865*	*839*	*813*

°C		°C		°C		°C		°C	
26	0.996 786	29	0.995 948	32	0.995 030	35	0.994 036	38	0.992 969
27	0.996 516	30	0.995 650	33	0.994 707	36	0.993 688	39	0.992 598
28	0.996 236	31	0.995 344	34	0.994 375	37	0.993 333	40	0.992 220

Density of heavy water (100% D_2O, 760 torr, air-free)

°C	kg dm^{-3}	Reference	°C	kg dm^{-3}	Reference
3.8	1.105 30	4a	20	1.105 24	4a
5	1.105 46	4a	25	1.104 34	6
10	1.105 85	4a	30	1.103 12	6
11.23	1.105 93*	5	35	1.101 64	6
15	1.105 74	4a	40	1.099 86	6

* Maximum density.

Specific heat capacity of water between 0 and 100 °C (at 760 torr)[7]

J g^{-1} K^{-1}

°C	0	1	2	3	4	5	6	7	8	9
0	4.2174	4.2138	4.2104	4.2074	4.2048	4.2019	4.1996	4.1974	4.1954	4.1936
10	4.1919	4.1904	4.1890	4.1877	4.1866	4.1855	4.1846	4.1837	4.1829	4.1822
20	4.1816	4.1810	4.1805	4.1801	4.1797	4.1793	4.1790	4.1787	4.1785	4.1783
30	4.1782	4.1781	4.1780	4.1780	4.1779	4.1779	4.1780	4.1780	4.1781	4.1782
40	4.1783	4.1784	4.1786	4.1788	4.1789	4.1792	4.1794	4.1796	4.1799	4.1801
50	4.1804	4.1807	4.1811	4.1814	4.1817	4.1821	4.1825	4.1829	4.1833	4.1837
60	4.1841	4.1846	4.1850	4.1855	4.1860	4.1865	4.1871	4.1876	4.1882	4.1887
70	4.1893	4.1899	4.1905	4.1912	4.1918	4.1925	4.1932	4.1939	4.1946	4.1954
80	4.1961	4.1969	4.1977	4.1985	4.1994	4.2002	4.2011	4.2020	4.2029	4.2039
90	4.2048	4.2058	4.2068	4.2078	4.2089	4.2100	4.2111	4.2122	4.2133	4.2145
100	4.2156									

cal_{15} g^{-1} K^{-1} (calculated by the editors from the CIPM values)[7]

°C	0	1	2	3	4	5	6	7	8	9
	1. *0.*	1. *0.*	1. *0.*	1. *0.*	1. *0.*	1. *0.*	1. *0.*	1. *0.*	1. *0.*	1. *0.*
0	007 62	006 76	005 95	005 23	004 54	003 92	003 37	002 84	002 37	001 94
10	001 53	001 17	000 84	000 53	000 26	000 00	*999 78*	*999 57*	*999 38*	*999 21*
20	*999 07*	*998 92*	*998 81*	*998 71*	*998 61*	*998 52*	*998 45*	*998 38*	*998 33*	*998 28*
30	*998 26*	*998 23*	*998 21*	*998 21*	*998 18*	*998 18*	*998 21*	*998 21*	*998 23*	*998 26*
40	*998 28*	*998 30*	*998 35*	*998 40*	*998 42*	*998 49*	*998 54*	*998 59*	*998 66*	*998 71*
50	*998 78*	*998 85*	*998 95*	*999 02*	*999 09*	*999 19*	*999 28*	*999 38*	*999 47*	*999 57*
60	*999 67*	*999 78*	*999 88*	000 00	000 12	000 24	000 38	000 50	000 65	000 76
70	000 91	001 05	001 19	001 36	001 51	001 67	001 84	002 01	002 17	002 37
80	002 53	002 72	002 91	003 11	003 32	003 51	003 73	003 94	004 16	004 40
90	004 61	004 85	005 09	005 33	005 59	005 85	006 12	006 38	006 64	006 93
100	007 19									

For the triple and boiling points of water and melting point of ice see page 20 for the vapour pressure of water see pages 256–258.

Viscosity of water between 0 and 40 °C[8]

Temperature t in °C	Viscosity ratio $\eta_t/\eta_{20\,°C}$	Dynamic viscosity η in cP	Kinematic viscosity ν in cSt
0	1.788 5	1.792	1.792
5	1.517 0	1.520	1.520
10	1.304 3	1.306 9	1.307 3
15	1.136 0	1.138 3	1.139 3
20	1.000 0	1.002 0	1.003 8
25	0.888 5	0.890 3	0.892 9
30	0.795 9	0.797 5	0.801 0
35	0.717 9	0.719 3	0.723 6
40	0.651 8	0.653 1	0.658 2

Air

Standard density of dry air free of carbon dioxide (0 °C, 760 torr)[9]:
$\varrho_n(\text{air}) = 1.292\,8 \times 10^{-3}$ kg dm^{-3}

Standard conditions for air in spectroscopy:
760 torr, 15 °C, 0.03% CO_2, dry

Acceleration due to gravity

Standard acceleration due to gravity[10]:
$g_n = 980.665$ Gal (cm s^{-2})

International gravity formula[11] (based on the international terrestrial ellipsoid):

$$\gamma_0 = (980.632\,272 - 2.586\,145 \cos 2B + 0.002\,878 \cos 4B - 0.000\,004 \cos 6B)\ \text{Gal}$$

where γ_0 = acceleration due to gravity at sea level, B = latitude. This yields the following values for different degrees of latitude (calculated by the editors):

Latitude in °	γ_0 in Gal	γ_0/g_n	g_n/γ_0	Latitude in °	γ_0 in Gal	γ_0/g_n	g_n/γ_0
0	978.0490	0.997332	1.002675	45	980.6294	0.999964	1.000036
5	0881	372	635	46	7197	1.000056	0.999944
10	2043	491	516	47	8098	148	852
15	3940	684	321	48	8998	239	761
20	6517	947	057	49	9894	331	669
25	9694	0.998271	1.001732	50	981.0787	422	578
30	*979.3378*	*647*	*355*	*51*	*1673*	512	488
31	4165	727	275	52	2554	602	398
32	4968	809	193	53	3427	691	309
33	5785	892	109	54	4291	779	221
34	6614	977	025	55	5146	866	134
35	7456	0.999062	1.000938	56	5990	952	048
36	8308	149	851	57	6822	1.001037	0.998964
37	9170	237	763	58	7642	121	880
38	980.0041	326	674	59	8448	203	799
39	0920	416	585	60	9239	284	718
40	1805	506	494	65	982.2941	661	342
41	2696	597	403	70	6139	987	017
42	3591	688	312	75	8734	1.002252	0.997753
43	4490	780	220	80	983.0647	447	559
44	5391	872	128	85	1818	566	440
				90	2213	607	400

The true acceleration due to gravity is probably about 14 mGal less than the value calculated from the international gravity formula[12].

Several new determinations of the acceleration due to gravity have recently been made[13]. The reference value of the acceleration due to gravity in the Potsdam system has meanwhile been lowered by 14 mGal following the resolutions adopted by the International Association of Geodesy[14] and by the International Committee of Weights and Measures[15] under the powers conferred on it by the 11th General Conference of Weights and Measures[15].

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10 Conférence Générale des Poids et Mesures, *Comptes rendus des séances de la 3ᵉ Conférence générale des Poids et Mesures*, Paris 1901, Gauthier-Villars, Paris 1901, page 70.

Periodic System of the Elements[1]

For each element the following are given: atomic number (*italics*), symbol, atomic weight (relative atomic mass)[2]

Period	Group I a b	Group II a b	Group III a b	Group IV a b	Group V a b	Group VI a b	Group VII a b	Group VIII a b[3]
1	*1*.H 1.00797[4]							*2*.He 4 0026
2	*3* Li 6 939	*4* Be 9 0122	*5*.B 10 811[4]	*6*.C 12 01115[4]	*7*.N 14 0067	*8*.O 15 9994[4]	*9*.F 18.9984	*10*.Ne 20 179[6]
3	*11*.Na 22 9898	*12*.Mg 24 305	*13*.Al 26.9815	*14* Si 28 086[4]	*15*.P 30.9738	*16*.S 32 064[4]	*17*.Cl 35 453[6]	*18*.Ar 39 948
4 (3 d)	*19*.K 39 102	*20* Ca 40 08	*21* Sc 44 956	*22* Ti 47.90	*23* V 50.942	*24*.Cr 51 996	*25*.Mn 54 9380	*26*.Fe; *27*.Co, *28*.Ni 55 847[5] 58 9332 58 71
	29 Cu 63 546[6]	*30*.Zn 65.37	*31*.Ga 69 72	*32* Ge 72 59	*33*.As 74 9216	*34* Se 78 96	*35*.Br 79 904[6]	*36* Kr 83 80
5 (4 d)	*37* Rb 85.47	*38* Sr 87.62	*39*.Y 88 905	*40* Zr 91 22	*41* Nb 92.906	*42* Mo 95 94	*43*.Tc (99)*	*44* Ru, *45* Rh, *46* Pd 101.07 102 905 106 4
	47.Ag 107.868[6]	*48* Cd 112 40	*49* In 114 82	*50* Sn 118 69	*51* Sb 121.75	*52* Te 127 60	*53* I 126 9044	*54* Xe 131 30
6 (5 d) (4 f)	*55* Cs 132 905	*56* Ba 137 34	*57* La $\boxed{4f}$ 138 91	*72* Hf 178 49	*73* Ta 180 948	*74* W 183 85	*75* Re 186 2	*76* Os, *77* Ir, *78* Pt 190 2 192 2 195 09
	79 Au 196 967	*80* Hg 200 59	*81*.Tl 204 37	*82* Pb 207 19	*83* Bi 208 980	*84* Po (210)*	*85* At (210)	*86* Rn (222)
7 (6 d) (5 f)	*87* Fr (223)	*88* Ra (226)	*89* Ac $\boxed{5f}$ (227)					

Lanthanides (rare-earth elements)

$\boxed{4f}$	*58* Ce 140.12	*59* Pr 140 907	*60* Nd 144 24	*61* Pm (147)*	*62* Sm 150 35	*63* Eu 151 96	*64* Gd 157 25	*65* Tb 158 924	*66* Dy 162 50	*67* Ho 164 930	*68* Er 167 26	*69* Tm 168 934	*70* Yb 173 04	*71* Lu 174 97

Actinides

$\boxed{5f}$	*90* Th 232.038	*91* Pa (231)	*92* U 238 03	*93* Np (237)	*94* Pu (244)	*95* Am (243)	*96* Cm (247)	*97* Bk (247)	*98* Cf (252)*	*99* Es (254)	*100* Fm (257)	*101* Md (257)	*102* No (255)	*103* Lr (256)

[1] Adapted from EUCKEN, A (Ed), *Landolt-Börnstein, Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik*, vol 1 *Atom- und Molekularphysik*, Part 1 *Atome und Ionen*, 6th ed , Springer, Berlin, 1950, page 11

[2] Based on the assigned mass 12 for the carbon isotope ^{12}C and taken from the Table of Atomic Weights 1967 (International Union of Pure and Applied Chemistry, *Comptes rendus de la 24e Conférence, 1967*, Butterworth, London, 1968, page 130 sq) A value in parentheses is the mass number of the most stable known isotope or, when marked with an

Chemical Elements – Alphabetical Table

Name	Symbol	Atomic number	Atomic weight [1] 1967
Actinium	Ac	89	(227)
Aluminium	Al	13	26.9815
Americium	Am	95	(243)
Antimony	Sb	51	121.75
Argon	Ar	18	39.948
Arsenic	As	33	74.9216
Astatine	At	85	(210)
Barium	Ba	56	137.34
Berkelium	Bk	97	(247)
Beryllium	Be	4	9.0122
Bismuth	Bi	83	208.980
Boron	B	5	10.811 [2]
Bromine	Br	35	79.904 [3]
Cadmium	Cd	48	112.40
Caesium	Cs	55	132.905
Calcium	Ca	20	40.08
Californium	Cf	98	(252)*
Carbon	C	6	12.01115 [2]
Cassiopeium	Cp	See Lutetium	
Cerium	Ce	58	140.12
Chlorine	Cl	17	35.453 [3]
Chromium	Cr	24	51.996
Cobalt	Co	27	58.9332
Columbium	Cb	See Niobium	
Copper	Cu	29	63.546 [3]
Curium	Cm	96	(247)
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	(254)
Emanation	Em	See Radon	
Erbium	*Er*	*68*	*167.26*
Europium	Eu	63	151.96
Fermium	Fm	100	(257)
Fluorine	F	9	18.9984
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.59
Glucinium	Gl	See Beryllium	
Gold	Au	79	196.967
Hafnium	Hf	72	178.49
Helium	He	2	4.0026
Holmium	Ho	67	164.930
Hydrogen	H	1	1.00797 [2]
Illinium	Il	See Promethium	
Indium	In	49	114.82
Iodine	I	53	126.9044
Iridium	Ir	77	192.2
Iron	Fe	26	55.847 [3]
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lawrencium	Lr	103	(256)
Lead	Pb	82	207.19
Lithium	Li	3	6.939
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.305
Manganese	Mn	25	54.9380
Mendelevium	Md	101	(257)
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.94
Neodymium	Nd	60	144.24
Neon	Ne	10	20.179 [3]
Neptunium	Np	93	(237)
Nickel	Ni	28	58.71
Niobium	Nb	41	92.906
Niton	Nt	See Radon	
Nitrogen	N	7	14.0067
Nobelium	No	102	(255)
Osmium	Os	76	190.2
Oxygen	O	8	15.9994 [2]
Palladium	Pd	46	106.4
Phosphorus	P	15	30.9738
Platinum	Pt	78	195.09
Plutonium	Pu	94	(244)
Polonium	Po	84	(210)*
Potassium	K	19	39.102
Praseodymium	Pr	59	140.907
Promethium	Pm	61	(147)*
Protactinium	Pa	91	(231)
Radium	Ra	88	(226)
Radon	Rn	86	(222)
Rhenium	Re	75	186.2
Rhodium	Rh	45	102.905
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.07
Samarium	Sm	62	150.35
Scandium	Sc	21	44.956
Selenium	*Se*	34	78.96
Silicon	Si	14	28.086 [2]
Silver	Ag	47	107.868 [3]
Sodium	Na	11	22.9898
Strontium	Sr	38	87.62
Sulphur	S	16	32.064 [2]
Tantalum	Ta	73	180.948
Technetium	Tc	43	(99)*
Tellurium	Te	52	127.60
Terbium	Tb	65	158.924
Thallium	Tl	81	204.37
Thorium	Th	90	232.038
Thulium	Tm	69	168.934
Tin	Sn	50	118.69
Titanium	Ti	22	47.90
Tungsten	W	74	183.85
Uranium	U	92	238.03
Vanadium	V	23	50.942
Wolfram	W	See Tungsten	
Xenon	Xe	54	131.30
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.905
Zinc	Zn	30	65.37
Zirconium	Zr	40	91.22

[1] See footnote [2], page 231.
[2] See footnote [4], page 231.
[3] See footnote [5], page 231.

mbol	Name	Atomic number	Atomic weight[1] 1967
Ac	Actinium	89	(227)
Ag	Silver	47	107.868[3]
Al	Aluminium	13	26 9815
Am	Americium	95	(243)
Ar	Argon	18	39 948
As	Arsenic	33	74.9216
At	Astatine	85	(210)
Au	Gold	79	196 967
B	Boron	5	10 811[2]
Ba	Barium	56	137.34
Be	Beryllium	4	9 0122
Bi	Bismuth	83	208 980
Bk	Berkelium	97	(247)
Br	Bromine	35	79 904[3]
C	Carbon	6	12 01115[2]
Ca	Calcium	20	40 08
Cb	Columbium	See Nb	
Cd	Cadmium	48	112 40
Ce	Cerium	58	140 12
Cf	Californium	98	(252)*
Cl	Chlorine	17	35 453[3]
Cm	Curium	96	(247)
Co	Cobalt	27	58 9332
Cp	Cassiopeium	See Lu	
Cr	Chromium	24	51 996
Cs	Caesium	55	132 905
Cu	Copper	29	63 546[3]
Dy	Dysprosium	66	162 50
Em	Emanation	See Rn	
Er	Erbium	68	167 26
Es	Einsteinium	99	(254)
Eu	Europium	63	151 96
F	Fluorine	9	18 9984
Fe	Iron	26	55 847[3]
Fm	Fermium	100	(257)
Fr	Francium	87	(223)
Ga	Gallium	31	69 72
Gd	Gadolinium	64	157 25
Ge	Germanium	32	72 59
Gl	Glucinium	See Be	
H	Hydrogen	1	1 00797[2]
He	Helium	2	4 0026
Hf	Hafnium	72	178 49
Hg	Mercury	80	200 59
Ho	Holmium	67	164 930
I	Iodine	53	126 9044
Il	Illinium	See Pm	
In	Indium	49	114 82
Ir	Iridium	77	192 2
K	Potassium	19	39 102
Kr	Krypton	36	83 80
La	Lanthanum	57	138 91
Li	Lithium	3	6 939
Lr	Lawrencium	103	(256)
Lu	Lutetium	71	174 97
Md	Mendelevium	101	(257)
Mg	Magnesium	12	24 305
Mn	Manganese	25	54 9380

Symbol	Name	Atomic number	Atomic weight[1] 1967
Mo	Molybdenum	42	95 94
N	Nitrogen	7	14 0067
Na	Sodium	11	22 9898
Nb	Niobium	41	92.906
Nd	Neodymium	60	144 24
Ne	Neon	10	20.179[3]
Ni	Nickel	28	58 71
No	Nobelium	102	(255)
Np	Neptunium	93	(237)
Nt	Niton	See Rn	
O	Oxygen	8	15 9994[2]
Os	Osmium	76	190 2
P	Phosphorus	15	30.9738
Pa	Protactinium	91	(231)
Pb	Lead	82	207.19
Pd	Palladium	46	106.4
Pm	Promethium	61	(147)*
Po	Polonium	84	(210)*
Pr	Praseodymium	59	140 907
Pt	Platinum	78	195 09
Pu	Plutonium	94	(244)
Ra	Radium	88	(226)
Rb	Rubidium	37	85 47
Re	Rhenium	75	186 2
Rh	Rhodium	45	102.905
Rn	Radon	86	(222)
Ru	Ruthenium	44	101.07
S	Sulphur	16	32.064[2]
Sb	Antimony	51	121.75
Sc	Scandium	21	44 956
Se	Selenium	34	78 96
Si	Silicon	14	28 086[2]
Sm	Samarium	62	150.35
Sn	Tin	50	118 69
Sr	Strontium	38	87 62
Ta	Tantalum	73	180 948
Tb	Terbium	65	158.924
Tc	Technetium	43	(99)*
Te	Tellurium	52	127.60
Th	Thorium	90	232 038
Ti	Titanium	22	47.90
Tl	Thallium	81	204.37
Tm	Thulium	69	168.934
Tu	Tungsten	See W	
U	Uranium	92	238 03
V	Vanadium	23	50 942
W	Tungsten	74	183 85
Xe	Xenon	54	131 30
Y	Yttrium	39	88.905
Yb	Ytterbium	70	173 04
Zn	Zinc	30	65 37
Zr	Zirconium	40	91 22

[1] See footnote [2], page 231
[2] See footnote [4], page 231
[3] See footnote [5], page 231

Atomic number Z	Symbol	Element English French German	Atomic weight 1967[1] [or mol. wt.]	Valency	Melting point[2] at 760 mm Hg (unless otherwise stated) °C	Boiling point[2] at 760 mm Hg (unless otherwise stated) °C	Density[2] Gases: g/l at 760 mm Hg and 0 °C Others: g/cm³ or specific gravity 20°/4°C (unless otherwise stated)	Natural abundance: Earth's crust, hydrosphere, atmosphere[3] %	Natural abundance: Atmosphere (troposphere)[4] vol %	Natural abundance: Universe (atoms per 10⁶ Si atoms)[5]	Natural abundance: Human body[6] %	Natural isotopes[7]: Isotope (mass number A)	Relative abundance atoms %	Mass[8]	Mode of decay[9]	Energy in MeV and percentage of decay	Half-life[10]
1	H [H_2]	**Hydrogen**[11] Hydrogène Wasserstoff	1.00797[12] [2.01594]	1	−259.14	−252.5	gas 0.08988 liquid 0.070/−252°	0.88	0.00005	4.00×10^{10}	10.0	^{1}H(H) ^{2}H(D) ^{3}H(T)	99.985 0.015 see ref.[13]	1.00783 2.01410 3.016049	 β− no γ	 0.0181 (100%)	 12.26y
2	He	**Helium** Hélium Helium	4.0026	0	−272.2 at 26 atm	−268.6	gas 0.177	4.2×10^{-7}	0.000524	3.08×10^{9}		^{3}He ^{4}He	1.3×10^{-4} (in the atmosphere) ~100	3.01603 4.00260			
3	Li	**Lithium** Lithium Lithium	6.939	1	179	1317	solid 0.534 liquid 0.507/200°	0.006		100		^{6}Li ^{7}Li	7.42 92.58	6.01513 7.01601			
4	Be	**Beryllium** Béryllium Beryllium	9.0122	2	1278±5	2970	solid 1.848	5.3×10^{-4}		20		^{9}Be	100	9.01219			
5	B	**Boron** Bore Bor	10.811[12]	3	2300	(sublimes 2550)	crystalline 2.34 amorphous 2.37	0.0016		24	$<1.4\times10^{-5}$	^{10}B ^{11}B	19.6 80.4	10.01294 11.00931			
6	C	**Carbon** Carbone Kohlenstoff	12.01115[12]	2, 4	3550 (sublimes > 3500)	4827	amorphous 1.8–2.1 graphite 1.9–2.3 diamond 3.15–3.53	0.087	CO: 0–trace CO_2: 0.0314	3.5×10^{6}	18.0	^{12}C ^{13}C ^{14}C	98.89 1.11 see ref.[14]	12.00000 13.00335 14.00324	 β− no γ	 0.1567 (100%)	 5.77×10^{3}y
7	N [N_2]	**Nitrogen** Azote Stickstoff	14.0067 [28.0134]	3, 5	−209.86	−195.8	gas 1.25060 liquid 0.808/−195.8° solid 1.026/−252°	0.030	78.084	6.6×10^{6}	3.0	^{14}N ^{15}N	99.63 0.37	14.00307 15.00011			
8	O [O_2]	**Oxygen** Oxygène Sauerstoff	15.9994[12] [31.9988]	2	−218.4	−182.970	gas 1.4290 liquid 1.14/−182.96°	49.5	20.9476 (O_2) $2–7\times10^{-6}$ (O_3)	2.15×10^{7}	65.0	^{16}O ^{17}O ^{18}O	99.759 0.037 0.204	15.99491 16.99913 17.99916			
9	F [F_2]	**Fluorine** Fluor Fluor	18.9984 [37.9968]	1	−219.62 (freezing point)	−188.14	gas 1.696 liquid 1.108/−188.14°	0.028		1600	2×10^{-2}	^{19}F	100	18.9984			
10	Ne	**Neon** Néon Neon	20.179[15]	0	−248.67	−245.92	gas 0.89990 liquid 1.207/−245.92°	5×10^{-7}	0.001818	8.6×10^{6}		^{20}Ne ^{21}Ne ^{22}Ne	90.92 0.257 8.82	19.99244 20.99385 21.99138			
11	Na	**Sodium** Sodium Natrium	22.9898	1	97.81 ±0.03	892	solid 0.971	2.63		4.38×10^{4}	1.5×10^{-1}	^{23}Na	100	22.98977			
12	Mg	**Magnesium** Magnésium Magnesium	24.305	2	651	1107	solid 1.738	1.95		9.12×10^{5}	5×10^{-2}	^{24}Mg ^{25}Mg ^{26}Mg	78.70 10.13 11.17	23.98504 24.98584 25.98259			

13	Al	**Aluminium** **(Aluminum)** Aluminium Aluminium	26 9815	3	660 1	2467	solid	2.6989	7.57		9.48 × 10⁴	1.4 × 10⁻⁴	²⁷Al	100	26 98153			
14	Si	**Silicon** Silicium Silicium	28 086¹²	4	1410	2355	solid	2.33/25°	25 80		1 × 10⁴	2 × 10⁻³	²⁸Si ²⁹Si ³⁰Si	92.21 4.70 3 09	27 97693 28 97649 29.97376			
15	P	**Phosphorus** Phosphore Phosphor	30 9738	3, 5	yellow 44 1	280	yellow solid red solid black solid	1 82 2.20 2 25–2.69	0 09		1 × 10⁴	1.0	³¹P	100	30.97376			
16	S	**Sulphur** **(Sulfur)** *Soufre* Schwefel	32 064¹²	2, 4, 6	rhombic 112 8 mono- clinic 119 0	444 600	rhombic solid monoclinic, solid	2 07 1 957	0.048	0–0 0001 (SO₂)	3 75 × 10⁸	2.5 × 10⁻¹	³²S ³³S ³⁴S ³⁶S	95 0 0 76 4 22 0 014	31.97207 32.97146 33 96786 35 96709			
17	Cl [Cl₂]	**Chlorine** Chlore Chlor	35 453¹⁸ [70 906]	1, 3, 5, 7	−100 98 (freezing point)	−34 6	gas liquid	3.214 1 56/−33 6°	0.19		8850	1 5 × 10⁻¹	³⁵Cl ³⁷Cl	75 53 24.47	34 96885 36 96590			
18	Ar	**Argon** Argon Argon	39 948	0	−189 2 (freezing point)	−185 7	gas liquid solid	1 7837 1 402/−185 7° 1 65/−223°	3 6 × 10⁻⁴	0 934	1.5 × 10⁸		³⁶Ar ³⁸Ar ⁴⁰Ar	0.337 0 063 99 60	35.96755 37 96272 39.96238			
19	K	**Potassium** Potassium Kalium	39 102	1	63 65	754	solid	0 862	2 41		3160	2 × 10⁻¹	³⁹K ⁴⁰K ⁴¹K	93 10 0 0118 6 88	38 96371 39 96401 40.96184	 β⁻ γ K	 1.32(9%) 1.46 (11%) 1.51 (11%)	 1 3 × 10⁹ y
20	Ca	**Calcium** Calcium Calcium	40 08	2	842–848	1487	solid	1.55	3.38		4 90 × 10⁴	1 5	⁴⁰Ca ⁴²Ca ⁴³Ca ⁴⁴Ca ⁴⁶Ca ⁴⁸Ca	96 97 0 64 0 145 2.06 0 0033 0 18	39 96259 41.95863 42 95878 43 95549 45 95369 47 95236	 β⁻	 0 12	 >2 × 10¹⁶ y
21	Sc	**Scandium** Scandium Scandium	44.956	3	1539	2727	solid	2 992	5 1 × 10⁻⁴		28		⁴⁵Sc	100	44 95592			
22	Ti	**Titanium** Titane Titan	47 90	2, 3, 4	1675	3260	solid	4 54	0 41		2440	<2 × 10⁻⁶	⁴⁶Ti ⁴⁷Ti ⁴⁸Ti ⁴⁹Ti ⁵⁰Ti	7.93 7.28 73 94 5.51 5 34	45 95263 46 95176 47 94795 48 94787 49 94479			
23	V	**Vanadium** Vanadium Vanadium (Vanadin)	50 942	2, 3, 4, 5	1890 ± 10	~3000	solid	6 11/18 7°	0 014		220	3 × 10⁻⁵	⁵⁰V ⁵¹V	0 24 99.76	49 94716 50 94398	β⁻, K γ	 0.71 1 59	≈6 × 10¹⁶ y

	Element English French German *Latin*	Atomic weight 1967[1]	Valency	Melting point[2] at 760 mm Hg (unless otherwise stated) °C	Boiling point[2] at 760 mm Hg (unless otherwise stated) °C	Density[2] Gases: g/l at 760 mm Hg and 0 °C Others: g/cm³ or specific gravity 20 °/4 °C (unless otherwise stated)		Natural abundance Earth's crust, hydrosphere, atmosphere[3] %	Atmosphere (troposphere)[4] vol %	Universe (atoms per 10^6 Si atoms)[5]	Human body[6] %	Natural isotopes[7] Isotope (mass number A)	Relative abundance atoms %	Mass[8]	Mode of decay[9]	Energy in MeV and percentage of decay	Half-life[10]
	Chromium Chrome Chrom	51.996	2, 3, 6	1890	2482	solid	7.18–7.20	0.019		7800	$<9\times10^{-6}$	^{50}Cr ^{52}Cr ^{53}Cr ^{54}Cr	4.31 83.76 9.55 2.38	49.946 05 51.940 51 52.940 65 53.938 88			
n	**Manganese** Manganèse Mangan	54.9380	1, 2, 3, 4, 6, 7	1244±3	2097	solid	7.21–7.44	0.085		6850	3×10^{-5}	^{55}Mn	100	54.938 05			
:	**Iron** Fer Eisen *Ferrum*	55.847[15]	2, 3, 4, 6	1535	3000	solid	7.874	4.7		6.00×10^5	6×10^{-3}	^{54}Fe ^{56}Fe ^{57}Fe ^{58}Fe	5.82 91.66 2.19 0.33	53.939 62 55.934 93 56.935 39 57.933 27			
o	**Cobalt** Cobalt Cobalt	58.9332	2, 3	1492	2900	solid	8.9	0.0037		1800	$<4\times10^{-6}$	^{59}Co	100	58.933 19			
li	**Nickel** Nickel Nickel	58.71	0, 1, 2, 3	1453	2732	solid	8.902/25°	0.015		2.74×10^4	$<1.4\times10^{-5}$	^{58}Ni ^{60}Ni ^{61}Ni ^{62}Ni ^{64}Ni	67.88 26.23 1.19 3.66 1.08	57.935 34 59.930 78 60.931 05 61.928 35 63.927 96			
ɔu	**Copper** Cuivre Kupfer *Cuprum*	63.546[15]	1, 2	1083	2595	solid	8.96	0.010		212	1.4×10^{-4}	^{63}Cu ^{65}Cu	69.09 30.91	62.929 59 64.927 79			
Zn	**Zinc** Zinc Zink	65.37	2	419.505	907	solid	7.133/25°	0.012		486	3.3×10^{-3}	^{64}Zn ^{66}Zn ^{67}Zn ^{68}Zn ^{70}Zn	48.89 27.81 4.11 18.57 0.62	63.929 15 65.926 05 66.927 15 67.924 87 69.925 35			
Ga	**Gallium** Gallium Gallium	69.72	2, 3	29.78	2403	solid	5.907	0.0014		11.4		^{69}Ga ^{71}Ga	60.4 39.6	68.925 68 70.924 84			
Ge	**Germanium** Germanium Germanium	72.59	2, 4	937.4	2830	solid	5.323/25°	5.6×10^{-4}		50.5		^{70}Ge ^{72}Ge ^{73}Ge ^{74}Ge ^{76}Ge	20.52 27.43 7.76 36.54 7.76	69.924 28 71.921 74 72.923 36 73.921 15 75.921 36			
As	**Arsenic** Arsenic Arsen	74.9216	3, 5	crystalline 817 at 28 atm [illegible]		crystalline amorphous yellow: solid	5.73 4.73 1.97	5.5×10^{-4}		4.0	2×10^{-5}	^{75}As	100	74.921 58			

34	Se	**Selenium** Sélénium Selen	78.96	2, 4, 6	grey 217 red 70–180	684.9 ±1.0	grey red	4.79/25° 4.46	8×10^{-6}		67.6		^{74}Se	0.87	73.92247			
													^{76}Se	9.02	75.91923			
													^{77}Se	7.58	76.91993			
													^{78}Se	23.52	77.91735			
													^{80}Se	49.82	79.91651			
													^{82}Se	9.19	81.91666			
35	Br	**Bromine** Brome Brom	79.904[16]	1, 3, 5, 7	−7.2	58.78	gas liquid	7.59 3.12	6×10^{-4}		13.4		^{79}Br	50.54	78.91835			
													^{81}Br	49.46	80.91634			
36	Kr	**Krypton** Krypton Krypton	83.80	0 (2, 4)	−156.6	−152.30 ±0.10	gas	3.733	1.9×10^{-9}	0.000114	51.3		^{78}Kr	0.35	77.92037			
													^{80}Kr	2.27	79.91639			
													^{82}Kr	11.56	81.91348			
													^{83}Kr	11.55	82.91413			
													^{84}Kr	57.90	83.9115			
													^{86}Kr	17.37	85.91062			
37	Rb	**Rubidium** Rubidium Rubidium	85.47	1, 2, 3, 4	38.89	688	liquid solid	1.475/39.0° 1.532	0.029		6.5	1.7×10^{-8}	^{85}Rb	72.15	84.91171			
													^{87}Rb	27.85	86.90918	β^- no γ	0.27	4.7×10^{10} y
38	Sr	**Strontium** Strontium Strontium	87.62	2	769	1384	solid	2.54	0.014		18.9	2×10^{-4}	^{84}Sr	0.56	83.91338			
													^{86}Sr	9.86	85.90926			
													^{87}Sr	7.02	86.90889			
													^{88}Sr	82.56	87.90561			
39	Y	**Yttrium** Yttrium Yttrium	88.905	3	1495±5	2927	solid	4.45	0.0026		8.9		^{89}Y	100	88.90543			
40	Zr	**Zirconium** Zirconium Zirkonium (Zirkon)	91.22	2, 4	1852±2	3578	solid	6.53±0.01 (calc.)	0.021		54.5	3.5×10^{-4}	^{90}Zr	51.46	89.90432			
													^{91}Zr	11.23	90.90525			
													^{92}Zr	17.11	91.90459			
													^{94}Zr	17.40	93.90614			
													^{96}Zr	2.80	95.9082			
41	Nb (Cb)	**Niobium** Niobium Niob (Columbium)	92.906	2, 3, 4?, 5	2468±10	4927	solid	8.57	0.0019		1.00	1.4×10^{-4}	^{93}Nb	100	92.90602			
42	Mo	**Molybdenum** Molybdène Molybdän	95.94	2, 3, 4, 6	2610	5560	solid	10.22	0.0014		2.42	$<7\times10^{-6}$	^{92}Mo	15.84	91.90629			
													^{94}Mo	9.04	93.90474			
													^{95}Mo	15.72	94.90572			
													^{96}Mo	16.53	95.90455			
													^{97}Mo	9.46	96.90575			
													^{98}Mo	23.78	97.90551			
													^{100}Mo	9.13	99.90757			
43	Tc	**Technetium** Technétium Technetium	(99)*	3, 4, 6, 7	2200±50		solid	11.50 (calc.)					$^{92-103}$Tc $^{104-105}$Tc	artificial element; all very unstable, except ^{97}Tc, ^{98}Tc, ^{99}Tc (half-lives 2.6×10^{6} y, 1.5×10^{6} y, 2.12×10^{5} y)				

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Element: English / French / German / *Latin*	Atomic weight 1967[1]	Valency	Melting point[2] at 760 mm Hg (unless otherwise stated) °C	Boiling point[2] at 760 mm Hg (unless otherwise stated) °C	Density[2] Gases: g/l at 760 mm Hg and 0 °C; Others: g/cm³ or specific gravity 20°/4°C (unless otherwise stated)	Natural abundance: Earth's crust, hydrosphere, atmosphere[3] %	Natural abundance: Atmosphere (troposphere)[4] vol %	Natural abundance: Universe (atoms per 10⁶ Si atoms)[5]	Natural abundance: Human body[6] %	Natural isotopes[7]: Isotope (mass number A)	Natural isotopes: Relative abundance atoms %	Natural isotopes: Mass[8]	Natural isotopes: Mode of decay[9]	Natural isotopes: Energy in MeV and percentage of decay	Natural isotopes: Half-life[10]
Ruthenium	101.07	0, 1, 2, 3, 4, 5, 6, 7, 8	2250	(3900)	solid 12.41	2×10^{-6}		1.49		^{96}Ru	5.51	95.9076			
Ruthénium										^{98}Ru	1.87	97.9055			
Ruthenium										^{99}Ru	12.72	98.90608			
										^{100}Ru	12.62	99.90302			
										^{101}Ru	17.07	100.90412			
										^{102}Ru	31.61	101.90372			
										^{104}Ru	18.58	103.90553			
Rhodium / Rhodium / Rhodium	102.905	2, 3, 4, 5	1960	(3727 ±100)	solid 12.41	1×10^{-7}		0.214		^{103}Rh	100	102.9048			
Palladium	106.4	2, 3, 4	1552	(2927)	solid 12.02	1×10^{-6}		0.675		^{102}Pd	0.96	101.90494			
Palladium										^{104}Pd	10.97	103.90356			
Palladium										^{105}Pd	22.23	104.90464			
										^{106}Pd	27.33	105.9032			
										^{108}Pd	26.71	107.90392			
										^{110}Pd	11.81	109.9045			
Silver / Argent	107.868[15]	1, 2	960.8	2112	solid 10.50	1×10^{-5}		0.26	$<1\times10^{-6}$	^{107}Ag	51.82	106.90497			
Silber / *Argentum*										^{109}Ag	48.18	108.9047			
Cadmium	112.40	2	321.03	765	solid 8.65	3×10^{-5}		0.89	4.3×10^{-5}	^{106}Cd	1.22	105.90595			
Cadmium										^{108}Cd	0.88	107.904			
Cadmium										^{110}Cd	12.39	109.90297			
										^{111}Cd	12.75	110.90415			
										^{112}Cd	24.07	111.90284			
										^{113}Cd	12.26	112.90461			
										^{114}Cd	28.86	113.90357			
										^{116}Cd	7.58	115.90501			
Indium	114.82	1, 2, 3	156.61	2000 ± 10	solid 7.31	1×10^{-5}		0.11		^{113}In	4.28	112.90428			
Indium / Indium										^{115}In	95.72	114.90407	β⁻	0.6 (100%)	6×10^{14} y
Tin	118.69	2, 4	231.91	2270	cubic (α) solid 5.750; tetragonal (β) solid 7.31	0.0035		1.33	4.3×10^{-5}	^{112}Sn	0.96	111.90494			
Etain										^{114}Sn	0.66	113.90296			
Zinn										^{115}Sn	0.35	114.90353			
Stannum										^{116}Sn	14.30	115.90211			
										^{117}Sn	7.61	116.90306			
										^{118}Sn	24.03	117.90179			
										^{119}Sn	8.58	118.90339			
										^{120}Sn	32.85	119.90213			
										^{122}Sn	4.92	121.90341			
										^{124}Sn	5.94	123.90524			

51	Sb	Antimony Antimoine Antimon *Stibium*	121 75	3, 5	630 5	1380	solid	6 691	6.5×10^{-5}		0.246	$<1.3\times10^{-4}$	^{121}Sb ^{123}Sb	57.25 42.75	120 90375 122.90415			
52	Te	Tellurium Tellure Tellur	127 60	2, 4, 6	449 5 ±0 3	989 8 ±3 8	rhombic	6.24	1×10^{-6}		4 67		^{120}Te ^{122}Te ^{123}Te ^{124}Te ^{125}Te ^{126}Te ^{128}Te ^{130}Te	0 089 2 46 0 87 4 61 6 99 18 71 31.79 32 48	119 90451 121 9030 122.90418 123 90276 124 90442 125.90324 127 90471 129 9067			
53	I	Iodine Iode Jod	126 9044	1, 3, 5, 7	113 5	184.35	gas solid	11.27 4 93	6×10^{-6}	0–1×10^{-6} (I_2)	0 80	4×10^{-6}	^{127}I	100	126 90435			
54	Xe	Xenon Xénon Xenon	131 30	0 (2, 4, 6)	−111 9	−107.1 ±3	gas liquid	5 887 ± 0.009 3 52/ −109°	2.4×10^{-9}	8.7×10^{-6}	4 0		^{124}Xe ^{126}Xe ^{128}Xe ^{129}Xe ^{130}Xe ^{131}Xe ^{132}Xe ^{134}Xe ^{136}Xe	0 096 0 090 1.92 26 44 4 08 21 18 26 89 10 44 8 87	123 90612 125 90417 127.90354 128 90478 129 90351 130.90509 131 90416 133.9054 135.90722			
55	Cs	Caesium (Cesium) Césium Caesium	132.905	1	28 5	690	solid	1 873	6.5×10^{-4}		0 456	$<1.4\times10^{-8}$	^{133}Cs	100	132.90509			
56	Ba	Barium Baryum Barium	137.34	2	725	1140	solid	3 5	0 026		3 66	2.3×10^{-6}	^{130}Ba ^{132}Ba ^{134}Ba ^{135}Ba ^{136}Ba ^{137}Ba ^{138}Ba	0 101 0 097 2 42 6 59 7.81 11.32 71 66	129 90625 131.90512 133 90431 134 9057 135 90436 136 90556 137.90501			
57	La	Lanthanum Lanthane Lanthan	138 91	3	920	3469	solid	5 98–6 186	0 0017		2 00		^{138}La ^{139}La	0 089 99 911	137.90681 138 90606	β^- γ K	0.205 (30%) 0.54 (15%) 0 81 (30%) 1.43 (70%) (70%)	1.1×10^{11} y
58	Ce	Cerium *Cérium* Cer	140 12	3, 4	795	3468	cubic hexagonal	α 8 23 β 6 66	0 0043		2.26		^{136}Ce ^{138}Ce ^{140}Ce ^{142}Ce	0.193 0.250 88.48 11.07	135.9071 137.90572 139 90528 141.90904	 α	 1.5	 5×10^{15} y

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59	Pr	**Praseodymium** Praséodyme Praseodym	140.907	3, 4	935	3127	hexagonal cubic	α 6.782 β 6.64	5.2×10^{-4}		0.40		^{141}Pr	100	140.90739			
60	Nd	**Neodymium** Néodyme Neodym	144.24	3	1024	3027	hexagonal cubic	α 7.004 β 6.80	0.0022		1.44		^{142}Nd	27.11	141.90748			
													^{143}Nd	12.17	142.90962			
													^{144}Nd	23.85	143.9099	α	1.8	$\approx 5 \times 10^{15}$ y
													^{145}Nd	8.30	144.91216			
													^{146}Nd	17.22	145.91269			
													^{148}Nd	5.73	147.91648			
													^{150}Nd	5.62	149.92071			
61	Pm	**Promethium** Prométhium Promethium	(147)*	3	1035	2730							^{147}Pm	see ref.[16]	146.91486	β^-	0.225 (100%) 0.10 (10^{-2}%)	2.5 y
62	Sm	**Samarium** Samarium Samarium	150.35	2, 3	1072	1900	rhombohedral	α 7.536 β 7.40	6×10^{-4}		0.664		^{144}Sm	3.09	143.91165			
													^{147}Sm	14.97	146.91462	α	2.24	1.06×10^{11} y
													^{148}Sm	11.24	147.91456	α	2.14	1.2×10^{13} y
													^{149}Sm	13.83	148.91693	α	1.84	$\sim 4 \times 10^{14}$ y
													^{150}Sm	7.44	149.91701			
													^{152}Sm	26.72	151.91949			
													^{154}Sm	22.71	153.92201			
63	Eu	**Europium** Europium Europium	151.96	2, 3	826	1439	solid	5.259	9.9×10^{-5}		0.187		^{151}Eu	47.82	150.91963			
													^{153}Eu	52.18	152.92086			
64	Gd	**Gadolinium** Gadolinium Gadolinium	157.25	3	1312	~3000	hexagonal cubic	α 7.895 β 7.80	5.9×10^{-4}		0.684		^{152}Gd	0.20	151.91953	α	2.15	1.1×10^{14} y
													^{154}Gd	2.15	153.92072			
													^{155}Gd	14.73	154.92259			
													^{156}Gd	20.47	155.9221			
													^{157}Gd	15.68	156.92394			
													^{158}Gd	24.87	157.9241			
													^{160}Gd	21.90	159.92712			
65	Tb	**Terbium** Terbium Terbium	158.924	3, 4	1356	2800	solid	8.272	8.5×10^{-5}		0.0956		^{159}Tb	100	158.92495			
66	Dy	**Dysprosium** Dysprosium Dysprosium	162.50	3	1407	2600	solid	8.536	4.2×10^{-4}		0.556		^{156}Dy	0.052	155.92376			
													^{158}Dy	0.090	157.92396			
													^{160}Dy	2.29	159.92483			
													^{161}Dy	18.88	160.9266			
													^{162}Dy	25.53	161.92647			
													^{163}Dy	24.97	162.92837			
													[illegible]	[illegible]	[illegible]			

67	Ho	Holmium Holmium Holmium	164 930	3	1461	2600	solid	8 803	1.1×10⁻⁴	0 118		^{165}Ho	100	[illegible]			
68	Er	Erbium Erbium Erbium	167 26	3	1497	2900	solid	9 051	2.3×10⁻⁴	0 316		^{162}Er	0.136	161 92878			
												^{164}Er	1.56	163 92929			
												^{166}Er	33 41	165.9304			
												^{167}Er	22 94	166 93205			
												^{168}Er	27 07	167.93238			
												^{170}Er	14 88	169 93551			
69	Tm	Thulium Thulium Thulium	168 934	2, 3	1545	1727	solid	9 332	1 9×10⁻⁸	0 0318		^{169}Tm	100	168 93435			
70	Yb	Ytterbium Ytterbium Ytterbium	173 04	2, 3	824±5	1427	cubic	α 6 977 β 6.54	2 5×10⁻⁴	0 220		^{168}Yb	0 135	167.9339			
												^{170}Yb	3 03	169.93488			
												^{171}Yb	14.31	170 93646			
												^{172}Yb	21 82	171.93656			
												^{173}Yb	16 13	172.9383			
												^{174}Yb	31 84	173 93902			
												^{176}Yb	12.73	175 94274			
71	Lu (Cp)	Lutetium (Lutecium) Lutetium Lutetium (Cassiopeium)	174.97	3	1652	3327	solid	9 842	7×10⁻⁶	0 050		^{175}Lu	97 41	174 94089			
												^{176}Lu	2 59	175 94274	β⁻	0 42 (100%)	2.1×10¹⁰y
															γ	0 0883 (100%) 0.202 (100%) 0.309 (100%)	
72	Hf	Hafnium Hafnium Hafnium	178 49	4	2150	5400	solid	13.29	4 2×10⁻⁴	0 438		^{174}Hf	0 18	173 94026	α	≈2.5	4.3×10¹⁵y
												^{176}Hf	5 20	175 94165			
												^{177}Hf	18 50	176 94348			
												^{178}Hf	27 14	177 94387			
												^{179}Hf	13 75	178 94602			
												^{180}Hf	35 24	179 94681			
73	Ta	Tantalum Tantale Tantal	180 948	2, 3, 4, 5	2996	5425 ±100	solid	16 6	8×10⁻⁴	0 065		^{180}Ta	0.0123	179 94752			
												^{181}Ta	99 988	180 94798			
74	W	Tungsten Tungstène Wolfram	183 85	2, 3, 4, 5, 6	3380	5927	solid	19 3	0 0064	0 49		^{180}W	0 14	179 94698			
												^{182}W	26 41	181 94827			
												^{183}W	14.40	182 95029			
												^{184}W	30 64	183 95099			
												^{186}W	28 41	185 95434			
75	Re	Rhenium Rhénium Rhenium	186 2	1, 2, 3, 4, 5, 6, 7	3180	5627 (estimated)	solid	21 02	1×10⁻⁷	0.135		^{185}Re	37.07	184.95302			
												^{187}Re	62 93	186 95737	β⁻	≤0 008	7×10¹⁰y

For footnotes see page 247.

Z Atomic number	Symbol	Element English French German *Latin*	Atomic weight 1967[1]	Valency	Melting point[2] at 760 mm Hg (unless otherwise stated) °C	Boiling point[2] at 760 mm Hg (unless otherwise stated) °C	Density[2] Gases: g/l at 760 mm Hg and 0 °C Others: g/cm³ or specific gravity 20°/4°C (unless otherwise stated)	Natural abundance: Earth's crust, hydrosphere, atmosphere[3] %	Natural abundance: Atmosphere (troposphere)[4] vol %	Natural abundance: Universe (atoms per 10^6 Si atoms)[5]	Natural abundance: Human body[6] %	Natural isotopes[7]: Isotope (mass number A)	Natural isotopes: Relative abundance atoms %	Natural isotopes: Mass[8]	Natural isotopes: Mode of decay[9]	Natural isotopes: Energy in MeV and percentage of decay	Natural isotopes: Half-life[10]
76	Os	**Osmium** Osmium Osmium	190.2	2, 3, 4, 8	3000 ± 10	(5000)	solid 22.57 (heaviest element)	1×10^{-6}		1.00		^{184}Os	0.018	183.95256			
												^{186}Os	1.59	185.95394			
												^{187}Os	1.64	186.95596			
												^{188}Os	13.3	187.95597			
												^{189}Os	16.1	188.95825			
												^{190}Os	26.4	189.9586			
												^{192}Os	41.0	191.96141			
77	Ir	**Iridium** Iridium Iridium	192.2	3, 4	2443	(4527 ± 100)	solid 22.42/17°	1×10^{-7}		0.821		^{191}Ir	37.3	190.96085			
												^{193}Ir	62.7	192.96328			
78	Pt	**Platinum** Platine Platin	195.09	1, 2, 3, 4	1769	(3827 ± 100)	solid 21.45	5×10^{-7}		1.625		^{190}Pt	0.0127	189.95995	α	3.11	7×10^{11} y
												^{192}Pt	0.78	191.96143	α	~2.6	~10^{15} y
												^{194}Pt	32.9	193.96281			
												^{195}Pt	33.8	194.96482			
												^{196}Pt	25.3	195.96498			
												^{198}Pt	7.21	197.96753			
79	Au	**Gold** Or Gold *Aurum*	196.967	1, 3	1063.0	2966	solid 19.32	5×10^{-7}		0.145	$<1 \times 10^{-6}$	^{197}Au	100	196.96655			
80	Hg	**Mercury** Mercure Quecksilber *Hydrargyrum*	200.59	1, 2	−38.87	356.58	14.43/−38.87° 13.595/0° 13.546/20°[17]	4×10^{-5}		0.284		^{196}Hg	0.146	195.96582			
												^{198}Hg	10.02	197.96677			
												^{199}Hg	16.84	198.96826			
												^{200}Hg	23.13	199.96834			
												^{201}Hg	13.22	200.97032			
												^{202}Hg	29.80	201.97063			
												^{204}Hg	6.85	203.97348			
81	Tl	**Thallium** Thallium Thallium	204.37	1, 3	303.5	1457 ± 10	solid 11.85	3×10^{-5}		0.108		^{203}Tl	29.50	202.97233			
												^{205}Tl	70.50	204.97446			
												^{206}Tl (Radium E″)		205.97608	β− no γ	1.51	4.20 min
												^{207}Tl (Actinium C″)		206.97745	β− γ	1.44 0.89 (≈0.2%)	4.78 min
												^{208}Tl (Thorium C″)		207.98201	β− γ	1.80 (50%) 1.52 (21%) 1.28 (25%) 2.615 (100%) 0.511 (25%) 0.860 (12%) 0.583 [illegible]	3.1 min

													(Radium C″)			γ	0.297 (100%)	
																	0.783 (100%)	
																	1.1	
82	Pb	**Lead** Plomb Blei *Plumbum*	207.19	2, 4	327.5	1744	*solid*	11.35	0.0018		0.47	1.1×10^{-4}	^{204}Pb	1.48	203.97307	α	2.6	1.4×10^{17} y
													^{206}Pb (Radium G)	23.6	205.97446			
													^{207}Pb	22.6	206.9759			
													^{208}Pb	52.3	207.97664			
													^{210}Pb (Radium D)		209.98418	β^-	0.015 (85%)	21 y
																	0.061 (15%)	
																γ	0.047 (85%)	
													^{211}Pb (Actinium B)		210.9888	β^-	1.39 (80%)	36.1 min
																	0.56	
																	0.065	
																γ	0.083 (5%)	
																	0.404 (6%)	
																	0.829 (13%)	
													^{212}Pb (*Thorium B*)		211.99190	β^-	0.34 (84%)	10.64 h
																	0.58 (12%)	
																γ	0.1151	
																	0.1764	
																	0.2383 (80%)	
																	0.3 (4%)	
																	0.4152	
													^{214}Pb (Radium B)		213.99976	β^-	0.7 (6%)	26.8 min
																	1.03	
																γ	0.352	
																(>10)	0.053–0.259	
83	Bi	**Bismuth** Bismuth Wismut	208.980	3, 5	271.3	1560±5	solid	9.747	2×10^{-4}		0.144		^{209}Bi	100	208.98042			
													^{210}Bi (Radium E)		209.98411	α	4.7 ($\approx10^{-5}$%)	5.00 d
																β^-	1.16	
																no γ		
													^{211}Bi (Actinium C)		210.98729	α	6.617 (83%)	2.15 min
																	6.273 (17%)	
																β^-	0.06 (0.3%)	
																γ	0.351 (17%)	
													^{212}Bi (Thorium C)		211.99127	α	6.049 (25%)	60.6 min
																	6.088 (10%)	
																β^-	0.085–2.25 (65%)	
																γ	0.040 (25%)	
																(>10)	0.727	
																	0.124–2.2	
													^{214}Bi (Radium C)		213.99863	α	5.5 (0.04%)	19.7 min
																β^-	0.4–3.2 ($\geq$99%)	
																γ	0.609	
																(>10)	1.12	
																	1.76	
																	0.45–2.43	
													^{215}Bi		215.0019	β^-		8 min

For footnotes see page 24–

Symbol	Element English French German	Atomic weight 1967[1]	Valency	Melting point[2] at 760 mm Hg (unless otherwise stated) °C	Boiling point[2] at 760 mm Hg (unless otherwise stated) °C	Density[2] Gases: g/l at 760 mm Hg and 0 °C Others: g/cm³ or specific gravity 20 °/4 °C (unless otherwise stated)	Natural abundance: Earth's crust, hydrosphere, atmosphere[3] %	Natural abundance: Atmosphere (troposphere)[4] vol %	Natural abundance: Universe (atoms per 10⁶ Si atoms)[5]	Natural abundance: Human body[6] %	Natural isotopes[7]: Isotope (mass number A)	Relative abundance atoms %	Mass[8]	Mode of decay[9]	Energy in MeV and percentage of decay	Half-life[10]
Po	**Polonium** Polonium Polonium	(210)*	(2, 4, 6)	254	962	solid α9.32	2.1×10^{-14}				^{210}Po (Radium F)		209.98287	α γ	5.30 0.79 (1.2×10^{-3}%)	138.40 d
											^{211}Po (Actinium C′)		210.98665	α γ	7.44 (99%) 6.90 (0.5%) 6.57 (0.5%) 0.88 (0.5%) 0.562 (0.5%)	0.52 s
											^{212}Po (Thorium C′)		211.98886	α	8.78	0.30 μs
											^{214}Po (Radium C′)		213.99519	α	7.68	164 μs
											^{215}Po (Actinium A)		214.99947	α β⁻	7.36 (≧99%) (0.005%)	0.0018 s
											^{216}Po (Thorium A)		216.00192	α β⁻	6.78 (99.986%) (0.014%)	0.16 s
											^{218}Po (Radium A)		218.00893	α β⁻	6.00 (≧99%) (0.02%)	3.05 min
At	**Astatine** Astatine (Astate) Astatin	(210)	(1, 3, 5, 7)				3×10^{-24}				^{215}At		214.99866	α	8.00	≈100 μs
											^{216}At		216.00241	α	7.79	≈300 μs
											^{218}At		218.00855	α	6.70 6.65	1.35 s
											^{219}At		219.01136	α β⁻	6.27	54 s
Rn (Em) (Nt)	**Radon** Radon Radon (Emanation) (Niton)	(222)	0	−71	−61.8	gas 9.73 liquid 4.4/−62° solid 4	6.2×10^{-16}				^{219}Rn (Actinon)		219.00952	α γ	6.81 (82%) 6.54 (13%) 6.41 (5%) 0.270 (13%) 0.399 (4.8%)	4.0 s
											^{220}Rn (Thoron)		220.0114	α γ	6.282 (≧99%) 5.747 (0.3%) 0.542 (≈0.3%)	51.5 s
											^{222}Rn (Radon)		222.01753	α γ	4.586 (≧99%) 4.98 (0.08%) 4.83 0.51 (≈0.08%)	3.823 d
Fr	**Francium** Francium Francium	(223)	1				1.3×10^{-21}				^{223}Fr (Actinium K)		223.0198	α β⁻ γ	5.34 (0.005%) 1.15 (≧99%) 0.049 (40%) 0.080 (24%)	22 min

88	Ra	Radium Radium Radium	(226)	2	700	<1737	solid	5?	9.5×10^{-11}	1.4×10^{-19}	^{223}Ra (Actinium X)	223 0187	α	5 71 (50%) 5 60 (24%) 5 23 (10%) 5 33–5.87	11.7 d
													γ (>10)	0 155 0.122 0 270 0 338 0 031–0 45	
											^{224}Ra (Thorium X)	224 020 22	α	5 68 (95%) 5 44 (5%)	3 64 d
													γ	0 240 98 (3.7%) 0 290 (8×10^{-3}%) 0 410 (4×10^{-3}%) 0 650 (9×10^{-3}%)	
											^{226}Ra	226 025 36	α	4.78 (95%) 4.59 (4%)	1622 y
													γ	0 187 (4%) 0 260 (0.001%) 0 420 0 64	
											^{228}Ra (Meso-thorium I)	228 031 23	β⁻ γ	0 055 ≈0 03	6.7 y
89	Ac	Actinium Actinium Actinium	(227)	3	1050	3200 ± 300 (estimated)	solid	10 07 (calc)	6.1×10^{-14}		^{227}Ac	227 027 81	α	4 949 (1%) 4 936 4 517–4 866	21 6 y
													β⁻ γ (9)	0 043 (99%) 0 009–0 190	
											^{228}Ac (Meso-thorium II)	228 031 17	β⁻	1.11 (53%) 0 45–2 18	6 13 h
													γ (>10)	0 057 0 10 0.91 0 08–0 966	
90	Th	Thorium Thorium Thorium	232.038	4	~1700	4000	solid	~11 66	0 0011		^{227}Th (Radio-actinium)	227.027 77	α	5 976 (24%) 6 036 (23%) 5.755 (2.1%) 5 667–6 007	18.17 d
													γ (>10)	0 050 (14%) 0.061 (9%) 0 236 (11%) 0 029–0.334	
											^{228}Th (Radio-thorium)	228 028 75	α	5 421 (71%) 5.338 (28%) 5.137–5 208	1 91 y
													γ	0 085 (1.6%) 0.134 (0 16%) 0 169 (0 13%) 0.205 (0 03%) 0 214 (0.27%)	

For footnotes see page 247

Z Atomic number	Symbol	Element English French German	Atomic weight 1967[1]	Valency	Melting point[2] at 760 mm Hg (unless otherwise stated) °C	Boiling point[2] at 760 mm Hg (unless otherwise stated) °C	Density[2] Gases: g/l at 760 mm Hg and 0 °C Others: g/cm³ or specific gravity 20 °/4 °C (unless otherwise stated)	Natural abundance: Earth's crust, hydrosphere, atmosphere[3] %	Natural abundance: Atmosphere (troposphere)[4] vol %	Natural abundance: Universe (atoms per 10⁶ Si atoms)[5]	Natural abundance: Human body[6] %	Natural isotopes[7]: Isotope (mass number A)	Natural isotopes[7]: Relative abundance atoms %	Natural isotopes[7]: Mass[8]	Natural isotopes[7]: Mode of decay[9]	Natural isotopes[7]: Energy in MeV and percentage of decay	Natural isotopes[7]: Half-life[10]
90	Th	**Thorium** (continued)										^{230}Th (Ionium)		230.03308	α γ	4.682 (76%) 4.615 (24%) 4.240–4.474 0.0677 (0.59%) 0.110 (1 × 10⁻⁴%) 0.144 (0.77%) 0.19 (1.4 × 10⁻²%) 0.203 (≈5 × 10⁻⁶%) 0.235 (≈5 × 10⁻⁶%) 0.255 (1.7 × 10⁻²%)	8 × 10⁴ y
												^{231}Th (Uranium Y)		231.03635	β⁻ γ (>10)	0.30 (78%) 0.084 (11%) 0.256 (13%) 0.017–0.31	25.6 h
												^{232}Th		232.03821	α γ	4.007 (76%) 3.99 (24%) 0.059 (24%)	1.39 × 10¹⁰ y
												^{234}Th (Uranium X_1)		234.04357	β⁻ γ	0.192 (65%) 0.10 (35%) 0.092 0.063 0.029	24.10 d
91	Pa	**Protactinium** Protactinium Protactinium	(231)	4, 5	~1230?		solid 15.37	9 × 10⁻¹¹				^{231}Pa		231.03594	α γ (>10)	5.001 (24%) 5.017 (23%) 5.046 (10%) 4.938 (22%) 4.666–4.971 0.29 0.027–0.356	3.43 × 10⁴ y
												^{234}Pa (Uranium X_2)			β⁻ γ (>10) IT	0.58 (99%) 2.31 (1%) 0.043 0.23–1.83	1.18 min
												^{234}Pa (Uranium Z)		234.04337	β⁻ γ (>10)	0.23–1.35 0.044 (92%) 0.100 (71%) 0.228 (33%)	6.66 h

92 U	Uranium Uranium Uran	238 03	3, 4, 1132.3 5, 6 ±0 8	[illegible]	[illegible]	[illegible]	(Uranium II)				[illegible]	[illegible]	
										γ	0.053 0.118		
							^{235}U (Actino-uranium)	0.720	235 04393	α	4.559 4.370 4 354 4 333 4.318 4.117	(6.7%) (25%) (35%) (14%) (8%) (5 8%)	7 13×10^{8} y
										γ	0 074 0 094 0 1096 0.144 0.165 0.185 0 203 0 2890 0 367 0 385	 (9%) (5%) (12%) (>4%) (55%) (>4%)	
							^{238}U (Uranium I)	99 27	238 05076	α	4 195 4 14	(77%) (23%)	4 51×10^{9} y
										γ	0 048	(23%)	

[1] See footnote [2], page 231
[2] From Hammond, C.R., in Weast et al (Eds), *Handbook of Chemistry and Physics*, 49th ed., The Chemical Rubber Co, Cleveland, 1968, page B-97, Hampel, C.A (Ed), *Rare Metals Handbook*, 2nd ed, Reinhold, London, 1961
[3] Values are total percentages in the lithosphere (outer 10 miles), hydrosphere and atmosphere (from Remy, H, *Lehrbuch der anorganischen Chemie*, 11th ed, vol. 2, Akademische Verlagsgesellschaft, Leipzig, 1961, page 769)
[4] Dry atmosphere at sea level. From *Manual of the ICAO Standard Atmosphere*, International Civil Aviation Organization, Montreal, 1964
[5] From Suess and Urey, *Rev mod Phys*, 28, 53 (1956)
[6] From Schroeder, H A, *J chron. Dis*, 18, 217 (1965), for As from Schroeder und Balassa, *J chron Dis*, 19, 85 (1966), for Zr from Schroeder und Balassa, *J chron Dis*, 19, 573 (1966), for Nb from Schroeder und Balassa, *J chron Dis*, 18, 229 (1965) See also 'Composition of the Body', pages 517–522
[7] From Heath, R L, in Weast et al. (Eds.), *Handbook of Chemistry and Physics*, 49th ed, The Chemical Rubber Co, Cleveland, 1968, page B-4
[8] Unified scale of atomic masses (^{12}C scale, see page 226) Values from König et al., *Nucl Phys*, 31, 18 (1962)
[9] α = alpha particle (helium nucleus = 2 protons + 2 neutrons), β^- = beta particle (electron), γ = gamma ray, K = orbital electron capture, IT = isomeric transition
[10] y = year, d = day, h = hour, min = minute, s = second.
[11] Normal molecular hydrogen is a mixture of *ortho-* and *para* hydrogen (molecules in which the two nuclei have respectively parallel and anti-parallel spins) in the proportions 3 1
[12] See footnote [4], page 231
[13] A disintegration product of ^{14}N in the atmosphere due to the action of cosmic rays. The ratio of ^{1}H to ^{3}H atoms in atmospheric hydrogen is of the order of 10^{18}. Cf Grosse et al, *Phys Rev*, 93, 250 (1954).
[14] A disintegration product of ^{14}N in the atmosphere due to the action of naturally occurring neutrons.
[15] See footnote [5], page 231
[16] A disintegration product of ^{146}Nd due to the action of naturally occurring neutrons.
[17] For density of mercury under standard conditions see page 230 For internationally accepted density values for mercury at different temperatures see Lindsay, R.B, in Gray, D E. (Ed.), *American Institute of Physics Handbook*, McGraw-Hill, New York, 1957, pages 2-140

Atomic number Z	Symbol	Transuranic element[1]	Atomic weight 1967[2]	Valency[3]	Melting point[3] °C	Boiling point[3] °C	Density[3] g/cm³	Isotopes: Isotope (mass number A)	Isotopes: Mass[5]	Isotopes: Mode of decay[6] (radiation)	Isotopes: Energy in MeV[4] (percentage of decay in brackets)	Isotopes: Half-life[7]
93	Np	Neptunium	(237)	3, 4, 5, 6	640±1		solid 18.0–20.45	^{237}Np	237.04803	α γ	4.787 (53%) 4.767 (29%) 4.52–4.87 0.020 0.087 (14%) 0.0296 (14%) 0.0568 (0.8%) 0.143 (0.1%) 0.175 (0.3%) 0.200	2.14×10^{6} y
94	Pu	Plutonium	(244)	3, 4, 5, 6	639.5±2	3235±19	solid α 19.84/25°	^{244}Pu		α		8.2×10^{7} y
95	Am	Americium	(243)	3, 4, 5, 6	>850		solid 11.7	^{243}Am	243.06138	α, γ		7950 y
96	Cm	Curium	(247)	3			solid ~7	^{247}Cm		α		1.6×10^{7} y
97	Bk	*Berkelium*	(247)	3, 4				^{247}Bk	247.07018	α, γ		1.4×10^{3} y
98	Cf	Californium	(252)*	3				^{252}Cf		α		2.65 y
99	Es	Einsteinium	(254)	3				^{254}Es	254.08811	α, γ		270 d
100	Fm	Fermium	(257)	3				^{257}Fm		α		80 d
101	Md	Mendelevium	(257)	3				^{257}Md		α, K		3.0 h
102	No	Nobelium	(255)					^{255}No		α		3.0 min
103	Lr	Lawrencium	(256)					^{256}Lr		α		45 s

[1] The transuranic elements have become known as artificially produced elements. However, since they have in the past occurred naturally (or are still, like ^{239}Pu, identifiable in very small amounts in nature) they can be regarded also as naturally occurring elements. In a sense they are elements which as a result of their short half-lives have become extinct.
[2] See footnote [2], page 231.
[3] From HAMMOND, C. R., in WEAST et al. (Eds.), *Handbook of Chemistry and Physics*, 49th ed., The Chemical Rubber Co., Cleveland, 1968, page B-97; HAMPEL, C. A. (Eds.), *Rare Metals Handbook*, 2nd ed., Reinhold, London, 1961.
[4] Values from HEATH, R. L., in WEAST et al. (Eds.), *Handbook of Chemistry and Physics*, 49th ed., The Chemical Rubber Co., Cleveland, 1968, page B-4.
[5] Unified scale of atomic masses (^{12}C scale; see page 226). Values from KÖNIG et al., *Nucl. Phys.*, 31, 18 (1962).
[6] α = alpha particle (helium nucleus = 2 protons + 2 neutrons), γ = gamma ray, K = orbital electron capture from K shell.
[7] y = year, d = day, h = hour, min = minute, s = second. Values from International Union of Pure and Applied Chemistry, *Comptes rendus de la 24e Conférence, 1967*, Butterworth, London, 1968, page 140.

Electronic Configurations of the Elements[1]

Z = atomic number, E_r = resonance energy (eV), E_i = ionization energy (eV), E_{r_1} = resonance energy of singly-ionized atom (eV)

Z	Element	E_r	E_i	E_{r_1}	K	L		M			N				O				P			Q
					1s	2s	2p	3s	3p	3d	4s	4p	4d	4f	5s	5p	5d	5f	6s	6p	6d	7s
1	H	10.19	13.60		1																	
2	He	21.20	24.58	40.8	2																	
3	Li	1.85	5.39	62.2	2	1																
4	Be	5.28	9.32	3.96	2	2																
5	B	4.96	8.30	9.10	2	2	1															
6	C	7.48	11.26	9.29	2	2	2															
7	N	10.3	14.54	11.4	2	2	3															
8	O	9.52	13.61	14.8	2	2	4															
9	F	12.98	17.42	20.42	2	2	5															
10	Ne	16.84	21.56	26.89	2	2	6															
11	Na	2.10	5.14	33.3	2	2	6	1														
12	Mg	4.34	7.64	4.42	2	2	6	2														
13	Al	3.14	5.98	7.42	2	2	6	2	1													
14	Si	4.92	8.15	6.86	2	2	6	2	2													
15	P	6.94	10.95	8.09	2	2	6	2	3													
16	S	6.86	10.36	9.84	2	2	6	2	4													
17	Cl	9.21	13.01	11.56	2	2	6	2	5													
18	Ar	11.53	15.75	13.47	2	2	6	2	6													
19	K	1.61	4.34	20.6	2	2	6	2	6		1											
20	Ca	2.93	6.11	3.12	2	2	6	2	6		2											
21	Sc	2.32	6.56	3.40	2	2	6	2	6	1	2											
22	Ti	1.97	6.83	3.66	2	2	6	2	6	2	2											
23	V	2.24	6.74	4.40	2	2	6	2	6	3	2											
24	Cr	2.89	6.76	6.00	2	2	6	2	6	5	1											
25	Mn	3.07	7.43	4.76	2	2	6	2	6	5	2											
26	Fe	3.21	7.90	5.20	2	2	6	2	6	6	2											
27	Co	3.57	7.86	5.83	2	2	6	2	6	7	2											
28	Ni	3.54	7.63	6.39	2	2	6	2	6	8	2											
29	Cu	3.79	7.72	8.26	2	2	6	2	6	10	1											
30	Zn	4.03	9.39	5.91	2	2	6	2	6	10	2											
31	Ga	3.07	6.00	8.78	2	2	6	2	6	10	2	1										
32	Ge	4.64	8.13	8.06	2	2	6	2	6	10	2	2										
33	As	6.28	9.81	9.14	2	2	6	2	6	10	2	3										
34	Se	6.32	9.75	10.39	2	2	6	2	6	10	2	4										
35	Br	8.32	11.84	12.21	2	2	6	2	6	10	2	5										
36	Kr	10.03	13.99	15.82	2	2	6	2	6	10	2	6										
37	Rb	1.59	4.17	17.8	2	2	6	2	6	10	2	6			1							
38	Sr	2.69	5.69	2.94	2	2	6	2	6	10	2	6			2							
39	Y	1.99	6.57	2.91	2	2	6	2	6	10	2	6	1		2							
40	Zr	2.02	6.95	3.47	2	2	6	2	6	10	2	6	2		2							
41	Nb	2.97	6.77	4.13	2	2	6	2	6	10	2	6	4		1							
42	Mo	3.18	7.18	6.08	2	2	6	2	6	10	2	6	5		1							
43	Tc	2.88	7.45	4.68	2	2	6	2	6	10	2	6	(5)		(2)							
44	Ru	3.26	7.5	6.29	2	2	6	2	6	10	2	6	7		1							
45	Rh	3.35	7.7	4.97	2	2	6	2	6	10	2	6	8		1							
46	Pd	4.22	8.33	8.12	2	2	6	2	6	10	2	6	10									
47	Ag	3.66	7.58	11.1	2	2	6	2	6	10	2	6	10		1							
48	Cd	3.80	8.99	5.47	2	2	6	2	6	10	2	6	10		2							
49	In	3.02	5.78	7.82	2	2	6	2	6	10	2	6	10		2	1						
50	Sn	4.30	7.33	7.30	2	2	6	2	6	10	2	6	10		2	2						
51	Sb	5.36	8.64	9.56	2	2	6	2	6	10	2	6	10		2	3						
52	Te	5.78	9.01	8.82	2	2	6	2	6	10	2	6	10		2	4						
53	I	7.67	10.44	10.04	2	2	6	2	6	10	2	6	10		2	5						
54	Xe	8.44	12.13	11.27	2	2	6	2	6	10	2	6	10		2	6						
55	Cs	1.38	3.89	15.2	2	2	6	2	6	10	2	6	10		2	6			1			
56	Ba	2.24	5.21	2.51	2	2	6	2	6	10	2	6	10		2	6			2			
57	La	1.64	5.61	1.75	2	2	6	2	6	10	2	6	10		2	6	1		2			
58	Ce		6.91	2.72	2	2	6	2	6	10	2	6	10	2	2	6			2			
59	Pr		5.76	2.81	2	2	6	2	6	10	2	6	10	3	2	6			2			
60	Nd		6.31	2.63	2	2	6	2	6	10	2	6	10	4	2	6			2			
61	Pm				2	2	6	2	6	10	2	6	10	5	2	6			2			
62	Sm	1.71	5.6	2.63	2	2	6	2	6	10	2	6	10	6	2	6			2			
63	Eu	1.74	5.67	2.95	2	2	6	2	6	10	2	6	10	7	2	6			2			
64	Gd	1.665	6.16	3.18	2	2	6	2	6	10	2	6	10	7	2	6	1		2			
65	Tb		6.74		2	2	6	2	6	10	2	6	10	8	2	6	1		2			
66	Dy		6.82		2	2	6	2	6	10	2	6	10	9	2	6	1		2			
67	Ho				2	2	6	2	6	10	2	6	10	10	2	6	1		2			
68	Er				2	2	6	2	6	10	2	6	10	11	2	6	1		2			
69	Tm	2.62?		2.68	2	2	6	2	6	10	2	6	10	13	2	6			2			
70	Yb	2.23	6.2	3.35	2	2	6	2	6	10	2	6	10	14	2	6			2			
71	Lu	2.16?	5.0	3.38	2	2	6	2	6	10	2	6	10	14	2	6	1		2			
72	Hf	2.19	5.5	3.43	2	2	6	2	6	10	2	6	10	14	2	6	2		2			
73	Ta	2.44	6	3.63	2	2	6	2	6	10	2	6	10	14	2	6	3		2			
74	W	2.49	7.98	4.48	2	2	6	2	6	10	2	6	10	14	2	6	4		2			
75	Re	3.57	7.88		2	2	6	2	6	10	2	6	10	14	2	6	5		2			
76	Os	2.80	8.7		2	2	6	2	6	10	2	6	10	14	2	6	6		2			
77	Ir	4.65	9.2		2	2	6	2	6	10	2	6	10	14	2	6	7		2			
78	Pt	4.04	8.97	6.38	2	2	6	2	6	10	2	6	10	14	2	6	9		1			
79	Au	4.63	9.22	7.81	2	2	6	2	6	10	2	6	10	14	2	6	10		1			
80	Hg	4.89	10.43	6.38	2	2	6	2	6	10	2	6	10	14	2	6	10		2			
81	Tl	3.28	6.11	9.39	2	2	6	2	6	10	2	6	10	14	2	6	10		2	1		
82	Pb	4.33	7.42	7.35	2	2	6	2	6	10	2	6	10	14	2	6	10		2	2		
83	Bi	4.04	8.0	8.63	2	2	6	2	6	10	2	6	10	14	2	6	10		2	3		
84	Po		7.25		2	2	6	2	6	10	2	6	10	14	2	6	10		2	4		
85	At				2	2	6	2	6	10	2	6	10	14	2	6	10		2	5		
86	Rn	6.78	10.75		2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		
87	Fr				2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		1
88	Ra	2.57	5.28	2.65	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		2
89	Ac				2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	1	2
90	Th			2.12	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	2	2
91	Pa				2	2	6	2	6	10	2	6	10	14	2	6	10	2	2	6	1	2
92	U	1.44	~4	3.21	2	2	6	2	6	10	2	6	10	14	2	6	10	3	2	6	1	2
93	Np				2	2	6	2	6	10	2	6	10	14	2	6	10	4	2	6	1	2
94	Pu				2	2	6	2	6	10	2	6	10	14	2	6	10	6	2	6		2
95	Am				2	2	6	2	6	10	2	6	10	14	2	6	10	7	2	6		2
96	Cm				2	2	6	2	6	10	2	6	10	14	2	6	10	7	2	6	1	2
97	Bk				2	2	6	2	6	10	2	6	10	14	2	6	10	8	2	6	1	2
98	Cf				2	2	6	2	6	10	2	6	10	14	2	6	10	10	2	6		2
99	Es				2	2	6	2	6	10	2	6	10	14	2	6	10	11	2	6		2
100	Fm				2	2	6	2	6	10	2	6	10	14	2	6	10	12	2	6		2
101	Md				2	2	6	2	6	10	2	6	10	14	2	6	10	13	2	6		2

[1] From Mavrodineanu and Boiteux, *L'analyse spectrale quantitative par la flamme*, Masson, Paris, 1954. Reproduced by permission of the authors and publishers.

Data for elements 94–101 from Weast et al. (Eds.), *Handbook of Chemistry and Physics*, 49th ed., The Chemical Rubber Co., Cleveland, 1968, page B 2.

Multiples of Atomic Weights of Important Elements

This table is based on the Table of Atomic Weights 1967 (see footnote [2], page 231)

Z	Symbol			0	1	2	3	4	5	6	7	8	9
1	H	Hydrogen	0	0.000 00	1.007 97	2.015 94	3.023 91	4.031 88	5.039 85	6.047 82	7.055 79	8.063 76	9.071
			10	10.079 70	11.087 67	12.095 64	13.103 61	14.111 58	15.119 55	16.127 52	17.135 49	18.143 46	19.151
			20	20.159 40	21.167 37	22.175 34	23.183 31	24.191 28	25.199 25	26.207 22	27.215 19	28.223 16	29.231
			30	30.239 10	31.247 07	32.255 04	33.263 01	34.270 98	35.278 95	36.286 92	37.294 89	38.302 86	39.310
			40	40.318 80	41.326 77	42.334 74	43.342 71	44.350 68	45.358 65	46.366 62	47.374 59	48.382 56	49.390
			50	50.398 50	51.406 47	52.414 44	53.422 41	54.430 38	55.438 35	56.446 32	57.454 29	58.462 26	59.470
			60	60.478 20	61.486 17	62.494 14	63.502 11	64.510 08	65.518 05	66.526 02	67.533 99	68.541 96	69.549
			70	70.557 90	71.565 87	72.573 84	73.581 81	74.589 78	75.597 75	76.605 72	77.613 69	78.621 66	79.629
			80	80.637 60	81.645 57	82.653 54	83.661 51	84.669 48	85.677 45	86.685 42	87.693 39	88.701 36	89.709
			90	90.717 30	91.725 27	92.733 24	93.741 21	94.749 18	95.757 15	96.765 12	97.773 09	98.781 06	99.789
			100	100.797 00	101.804 97	102.812 94	103.820 91	104.828 88	105.836 85	106.844 82	107.852 79	108.860 76	109.868
			110	110.876 70	111.884 67	112.892 64	113.900 61	114.908 58	115.916 55	116.924 52	117.932 49	118.940 46	119.948
			120	120.956 40	121.964 37	122.972 34	123.980 31	124.988 28	125.996 25	127.004 22	128.012 19	129.020 16	130.028
			130	131.036 10	132.044 07	133.052 04	134.060 01	135.067 98	136.075 95	137.083 92	138.091 89	139.099 86	140.107
			140	141.115 80	142.123 77	143.131 74	144.139 71	145.147 68	146.155 65	147.163 62	148.171 59	149.179 56	150.187
			150	151.195 50	152.203 47	153.211 44	154.219 41	155.227 38	156.235 35	157.243 32	158.251 29	159.259 26	160.267
			160	161.275 20	162.283 17	163.291 14	164.299 11	165.307 08	166.315 05	167.323 02	168.330 99	169.338 96	170.346
			170	171.354 90	172.362 87	173.370 84	174.378 81	175.386 78	176.394 75	177.402 72	178.410 69	179.418 66	180.426
			180	181.434 60	182.442 57	183.450 54	184.458 51	185.466 48	186.474 45	187.482 42	188.490 39	189.498 36	190.506
			190	191.514 30	192.522 27	193.530 24	194.538 21	195.546 18	196.554 15	197.562 12	198.570 09	199.578 06	200.586
6	C	Carbon	0	00.000 00	12.011 15	24.022 30	36.033 45	48.044 60	60.055 75	72.066 90	84.078 05	96.089 20	108.100 3
			10	120.111 50	132.122 65	144.133 80	156.144 95	168.156 10	180.167 25	192.178 40	204.189 55	216.200 70	228.211 8
			20	240.223 00	252.234 15	264.245 30	276.256 45	288.267 60	300.278 75	312.289 90	324.301 05	336.312 20	348.323 3
			30	360.334 50	372.345 65	384.356 80	396.367 95	408.379 10	420.390 25	432.401 40	444.412 55	456.423 70	468.434 8
			40	480.446 00	492.457 15	504.468 30	516.479 45	528.490 60	540.501 75	552.512 90	564.524 05	576.535 20	588.546 3
			50	600.557 50	612.568 65	624.579 80	636.590 95	648.602 10	660.613 25	672.624 40	684.635 55	696.646 70	708.657 8
			60	720.669 00	732.680 15	744.691 30	756.702 45	768.713 60	780.724 75	792.735 90	804.747 05	816.758 20	828.769 3
			70	840.780 50	852.791 65	864.802 80	876.813 95	888.825 10	900.836 25	912.847 40	924.858 55	936.869 70	948.880 8
			80	960.892 00	972.903 15	984.914 30	996.925 45	1008.936 60	1020.947 75	1032.958 90	1044.970 05	1056.981 20	1068.992 3
			90	1081.003 50	1093.014 65	1105.025 80	1117.036 95	1129.048 10	1141.059 25	1153.070 40	1165.081 55	1177.092 70	1189.103 8
7	N	Nitrogen	0	00.000 0	14.006 7	28.013 4	42.020 1	56.026 8	70.033 5	84.040 2	98.046 9	112.053 6	126.060 3
			10	140.067 0	154.073 7	168.080 4	182.087 1	196.093 8	210.100 5	224.107 2	238.113 9	252.120 6	266.127 3
			20	280.134 0	294.140 7	308.147 4	322.154 1	336.160 8	350.167 5	364.174 2	378.180 9	392.187 6	406.194 3
			30	420.201 0	434.207 7	448.214 4	462.221 1	476.227 8	490.234 5	504.241 2	518.247 9	532.254 6	546.261 3
			40	560.268 0	574.274 7	588.281 4	602.288 1	616.294 8	630.301 5	644.308 2	658.314 9	672.321 6	686.328 3
8	O	Oxygen	0	00.000 0	15.999 4	31.998 8	47.998 2	63.997 6	79.997 0	95.996 4	111.995 8	127.995 2	143.994 6
			10	159.994 0	175.993 4	191.992 8	207.992 2	223.991 6	239.991 0	255.990 4	271.989 8	287.989 2	303.988 6
			20	319.988 0	335.987 4	351.986 8	367.986 2	383.985 6	399.985 0	415.984 4	431.983 8	447.983 2	463.982 6
			30	479.982 0	495.981 4	511.980 8	527.980 2	543.979 6	559.979 0	575.978 4	591.977 8	607.977 2	623.976 6
			40	639.976 0	655.975 4	671.974 8	687.974 2	703.973 6	719.973 0	735.972 4	751.971 8	767.971 2	783.970 6
9	F	Fluorine	0	00.000 0	18.998 4	37.996 8	56.995 2	75.993 6	94.992 0	113.990 4	132.988 8	151.987 2	170.985 6
11	Na	Sodium	0	00.000 0	22.989 8	45.979 6	68.969 4	91.959 2	114.949 0	137.938 8	160.928 6	183.918 4	206.908 2
12	Mg	Magnesium	0	00.000	24.305	48.610	72.915	97.220	121.525	145.830	170.135	194.440	218.745
13	Al	Aluminium	0	00.000 0	26.981 5	53.963 0	80.944 5	107.926 0	134.907 5	161.889 0	188.870 5	215.852 0	242.833 5
14	Si	Silicon	0	00.000	28.086	56.172	84.258	112.344	140.430	168.516	196.602	224.688	252.774
15	P	Phosphorus	0	00.000 0	30.973 8	61.947 6	92.921 4	123.895 2	154.869 0	185.842 8	216.816 6	247.790 4	278.764 2
			10	309.738 0	340.711 8	371.685 6	402.659 4	433.633 2	464.607 0	495.580 8	526.554 6	557.528 4	588.502 2
16	S	Sulphur	0	00.000	32.064	64.128	96.192	128.256	160.320	192.384	224.448	256.512	288.576
			10	320.640	352.704	384.768	416.832	448.896	480.960	513.024	545.088	577.152	609.216
17	Cl	Chlorine	0	00.000	35.453	70.906	106.359	141.812	177.265	212.718	248.171	283.624	319.077
19	K	Potassium	0	00.000	39.102	78.204	117.306	156.408	195.510	234.612	273.714	312.816	351.918
20	Ca	Calcium	0	00.00	40.08	80.16	120.24	160.32	200.40	240.48	280.56	320.64	360.72
25	Mn	Manganese	0	00.000	54.938	109.876	164.814	219.752	274.690	329.628	384.566	439.504	494.442
26	Fe	Iron	0	00.000	55.847	111.694	167.541	223.388	279.235	335.082	390.929	446.776	502.623
27	Co	Cobalt	0	00.000 0	58.933 2	117.866 4	176.799 6	235.732 8	294.666 0	353.599 2	412.532 4	471.465 6	530.398 8
29	Cu	Copper	0	00.00	63.546	127.092	190.638	254.184	317.730	381.276	444.822	508.368	571.914
30	Zn	Zinc	0	00.00	65.37	130.74	196.11	261.48	326.85	392.22	457.59	522.96	588.33
33	As	Arsenic	0	00.000 0	74.921 6	149.843 2	224.764 8	299.686 4	374.608 0	449.529 6	524.451 2	599.372 8	674 294 4
35	Br	Bromine	0	00.000	79.904	159.808	239.712	319.616	399.520	479.424	559.328	639.232	719.136
53	I	Iodine	0	000.000 0	126.904 4	253.808 8	380.713 2	507.617 6	634.522 0	761.426 4	888.330 8	1015.235 2	1142.139 6
	H_2O	Water ($\frac{1}{2}H_2O$ = 9.007 67)	0	00.000 00	18.015 34	36.030 68	54.046 02	72.061 36	90.076 70	108.092 04	126.107 38	144.122 72	162.138 06
			10	180.153 40	198.168 74	216.184 08	234.199 42	252.214 76	270.230 10	288.245 44	306.260 78	324.276 12	342.291 45
	CH_2	Methylene	0	00.000 00	14.027 09	28.054 18	42.081 27	56.108 36	70.135 45	84.162 54	98.189 63	112.216 72	126.243 81
			10	140.270 90	154.297 99	168.325 08	182.352 17	196.379 26	210.406 35	224.433 44	238.460 53	252.487 62	266.514 71
			20	280.541 80	294.568 89	308.595 98	322.623 07	336.650 16	350.677 25	364.704 34	378.731 43	392.758 52	406.785 61
			30	420.812 70	434.839 79	448.866 88	462.893 97	476.921 06	490.948 15	504.975 24	519.002 33	533.029 42	547.056 51
			40	561.083 60	575.110 69	589.137 78	603.164 87	617.191 96	631.219 05	645.246 14	659.273 23	673.300 32	687.327 41
	CH_3	Methyl	0	00.000 00	15.035 06	30.070 12	45.105 18	60.140 24	75.175 30	90.210 36	105.245 42	120.280 48	135.315 54
			10	150.350 60	165.385 66	180.420 72	195.455 78	210.490 84	225.525 90	240.560 96	255.596 02	270.631 08	285.666 14
			20	300.701 20	315.736 26	330.771 32	345.806 38	360.841 44	375.876 50	390.911 56	405.946 62	420.981 68	436.016 74
	NH_4	Ammonium	0	00.000 00	18.038 58	36.077 16	54.115 74	72.154 32	90.192 90	108.231 48	126.270 06	144.308 64	162.347 22
			[illegible]	[illegible]	[illegible]	[illegible]	234.501 54	252.540 12	270.578 70	288.617 28	306.655 86	324.694 44	342.733 02

ımon chemical conversion factors

For converting		Factor	log_{10}	For converting		Factor	log_{10}
ɛtone	into acetoacetic acid	1.758	0.2450	Acetoacetic acid	into acetone	0.5689	0.7550−1
ɛtone	into β-hydroxybutyric acid	1.792	0.2533	β-Hydroxybutyric acid	into acetone	0.5579	0.7466−1
	into CaO	1.399	0.1458	CaO	into Ca	0.7147	0.8541−1
	into NaCl	1.648	0.2170	NaCl	into Cl	0.6066	0.7829−1
	into K_2O	1.205	0.0810	K_2O	into K	0.8302	0.9192−1
g	into MgO	1.658	0.2195	MgO	into Mg	0.6032	0.7805−1
a	into NaCl	2.542	0.4052	NaCl	into Na	0.3934	0.5948−1
a	into Na_2O	1.348	0.1297	Na_2O	into Na	0.7419	0.8704−1
	into P_2O_5	2.291	0.3600	P_2O_5	into P	0.4364	0.6399−1
	into H_3PO_4	3.164	0.5002	H_3PO_4	into P	0.3161	0.4998−1
	into SO_4	2.497	0.3974	SO_4	into S	0.4005	0.6026−1
	into H_2SO_4	3.059	0.4857	H_2SO_4	into S	0.3269	0.5144−1
rotein-N	into protein	6.25	0.7959	Protein	into protein-N	0.16	0.2041−1
mmonia-N	into ammonia	1.216	0.0849	Ammonia	into ammonia-N	0.8224	0.9151−1
reatine-N	into creatine	3.121	0.4943	Creatine	into creatine-N	0.3204	0.5057−1
reatinine-N	into creatinine	2.692	0.4301	Creatinine	into creatinine-N	0.3715	0.5700−1
Jrea-N	into urea	2.144	0.3312	Urea	into urea-N	0.4665	0.6689−1
Jric acid-N	into uric acid	3.001	0.4772	Uric acid	into uric acid-N	0.3333	0.5228−1
ipid-P	into phosphatides	23.5	1.3711				
ipid-P	into lecithin	25	1.3979	Lecithin	into lipid-P	0.040	0.6021−2

onversion of concentration units

In clinical chemistry, concentration data for fluids should be lated to the unit litre, those for solids to the unit kilogramme he use of ambiguous units like 'g%', 'mg%', 'p p m', etc. should avoided since they do not make it clear whether the data relate mass or to volume

onversion of mg/100 ml into mmol/l and vice versa

$$\text{mmol/l} = \frac{10 \times \text{mg/100 ml}}{\text{molecular weight}} = \frac{10000 \times \text{g/100 ml}}{\text{molecular weight}}$$

$$\text{mg/100 ml} = \frac{\text{mmol} \times \text{molecular weight}}{10}$$

Conversion of ml of gas/100 ml into mmol/l and vice versa
at 0 °C, 2.24 = millimolar normal volume of an ideal gas)

$$\text{mmol/l} = \frac{\text{ml/100 ml}}{2.24}$$

$$\text{ml/100 ml} = 2.24 \times \text{mmol/l}$$

Conversion of mg/100 ml into mEq/l and vice versa*

$$\text{mEq/l} = \frac{10 \times \text{mg/100 ml} \times \text{valency}}{\text{molecular weight}}$$

$$\text{mg/100 ml} = \frac{\text{mEq/l} \times \text{molecular weight}}{10 \times \text{valency}}$$

* Cf footnote on page 226.

Temperature variation of molarity and normality of aqueous solutions

The following conversion factors for temperatures deviating from the normal temperature of 20 °C are for 0.1-N solutions and assume a coefficient of expansion for glass of 0.000027[1]

Temperature	Factor
14 °C	1.0010
15 °C	1.0009
16 °C	1.0007
17 °C	1.0006
18 °C	1.0004
19 °C	1.0002
20 °C	1.0000
21 °C	0.9998
22 °C	0.9996
23 °C	0.9994
24 °C	0.9991
25 °C	0.9989
26 °C	0.9986
27 °C	0.9983

Reference

[1] From a more extensive table in KOLTHOFF, I M, *Die Maßanalyse*, part 2, Springer, Berlin, 1928, page 30

ICAO Standard Atmosphere[1]

The ICAO standard atmosphere is fundamentally defined in terms of an ideal air assumed to be devoid of moisture, water vapour and dust. It is based on accepted *standard values for the sea-level air*, as follows:

Atmospheric pressure $p_0 = 1.01325 \times 10^5$ N m^{-2} (= 760 torr)
Temperature $T_0 = 288.15$ K (= 15 °C)
Density $\varrho_0 = 1.2250$ kg m^{-3}
Acceleration due to gravity at 45° geographic latitude $g_0 = 9.80665$ m s^{-2}

The relative molecular mass M (molecular weight) of air at sea level is calculated from the equation of state of a perfect gas

$$\varrho = \frac{M\,p}{R\,T}$$

using the standard values for ϱ_0, p_0, T_0 at sea level and for the molar gas constant R, which is based on the relative atomic mass (atomic weight; see page 226) of the nuclide $^{12}C = 12$.

Molar gas constant $R = 8.3143$ J K^{-1} mol^{-1}
Relative molecular mass of air at sea level $M_0 = 28.9644$

Note that for the altitudes tabulated below the mean relative molecular mass of air is assumed to be the same as at sea level (M_0).

Composition of clean, dry atmospheric air near sea level

Gas	Relative molecular mass	vol %	Gas	Relative molecular mass	vol %
N_2	28.0134	78.084	CH_4	16.04303	*0.0002
O_2	31.9988	20.9476	N_2O	44.0128	0.00005
Ar	39.948	0.934	O_3	47.9982	*Summer 0–0.00
CO_2	44.00995	*0.0314			*Winter 0–0.00
Ne	20.183	0.001818	SO_2	64.0628	*0–0.0001
He	4.0026	0.000524	NO_2	46.0055	*0–0.000002
Kr	83.80	0.000114	NH_3	17.03061	*0 to traces
Xe	131.30	0.0000087	CO	28.01055	*0 to traces
H_2	2.01594	0.00005	I_2	253.8088	*0–0.000001

* The content of these gases may undergo significant variations from ti to time or from place to place relative to the normal indicated for the

Reference

[1] From the *Manual of the ICAO Standard Atmosphere*, 2nd ed., Internat Civil Aviation Organization, Montreal, 1964. Reproduced by kind mission of the publishers.

Geometric altitude (m)	Temperature (°C)	Atmospheric pressure mbar	Atmospheric pressure torr	p/p_0	Boiling point of water* (°C)	Density (kg m^{-3})	ϱ/ϱ_0	Velocity of sound (m s^{-1})	Dynamic viscosity (N s m^{-2})	Thermal conductivity (kcal m^{-1} s^{-1} deg^{-1})	Geometric altitude (ft)
-1000	21.501	1.13931+3	8.54554+2	1.12441+0	103.31	1.3470+0	1.0996+0	344.111	1.8206-5	6.1748-6	-3280
- 950	21.176	1.13272	8.49610	1.11791	103.15	1.3407	1.0945	343.921	1.8190	6.1687	-3116
- 900	20.851	1.12616	8.44689	1.11143	102.98	1.3344	1.0893	343.731	1.8175	6.1626	-2952
- 850	20.526	1.11963	8.39792	1.10499	102.81	1.3281	1.0842	343.541	1.8159	6.1566	-2788
- 800	20.201	1.11313	8.34917	1.09858	102.65	1.3219	1.0791	343.351	1.8144	6.1505	-2624
- 750	19.876	1.10666	8.30066	1.09219	102.48	1.3157	1.0740	343.161	1.8128	6.1444	-2460
- 700	19.550	1.10023	8.25237	1.08584	102.32	1.3095	1.0690	342.970	1.8113	6.1383	-2296
- 650	19.225	1.09382	8.20432	1.07952	102.15	1.3033	1.0639	342.780	1.8097	6.1323	-2132
- 600	18.900	1.08744	8.15649	1.07322	101.99	1.2971	1.0589	342.589	1.8081	6.1262	-1968
- 550	18.575	1.08110	8.10889	1.06696	101.83	1.2910	1.0539	342.399	1.8066	6.1201	-1804
- 500	18.250	1.07478+3	8.06151+2	1.06073+0	101.66	1.2849+0	1.0489+0	342.208	1.8050-5	6.1140-6	-1640.
- 450	17.925	1.06849	8.01436	1.05452	101.49	1.2788	1.0439	342.017	1.8035	6.1079	-1476.
- 400	17.600	1.06224	7.96743	1.04835	101.32	1.2727	1.0390	341.826	1.8019	6.1018	-1312.
- 350	17.275	1.05601	7.92073	1.04220	101.16	1.2667	1.0340	341.635	1.8003	6.0957	-1148.
- 300	16.950	1.04981	7.87425	1.03609	100.99	1.2607	1.0291	341.443	1.7988	6.0896	- 984
- 250	16.625	1.04365	7.82799	1.03000	100.82	1.2547	1.0242	341.252	1.7972	6.0835	- 820.
- 200	16.300	1.03751	7.78195	1.02394	100.66	1.2487	1.0193	341.061	1.7956	6.0774	- 656.
- 150	15.975	1.03140	7.73614	1.01791	100.49	1.2427	1.0145	340.869	1.7941	6.0713	- 492.
- 100	15.650	1.02532	7.69054	1.01191	100.33	1.2368	1.0096	340.678	1.7925	6.0652	- 328.
- 50	15.325	1.01927	7.64516	1.00594	100.16	1.2309	1.0048	340.486	1.7909	6.0591	- 164.
0	15.000	1.01325+3	7.60000+2	1.00000+0	100.00	1.2250+0	1.0000+0	340.294	1.7894-5	6.0530-6	[illegible]
50	14.675	1.00726	7.55505	9.94086-1	99.83	1.2191	9.9521-1	340.102	1.7878	6.0469	164.
100	14.350	1.00129	7.51032	9.88201	99.66	1.2133	9.9044	339.910	1.7862	6.0408	328.
150	14.025	9.95360+2	7.46581	9.82344	99.50	1.2075	9.8568	339.718	1.7847	6.0347	492.1
200	13.700	9.89454	7.42151	9.76515	99.33	1.2017	9.8094	339.525	1.7831	6.0286	656.2
250	13.375	9.83576	7.37743	9.70714	99.17	1.1959	9.7622	339.333	1.7815	6.0225	820.2
300	13.050	9.77727	7.33356	9.64942	99.00	1.1901	9.7152	339.141	1.7800	6.0164	984.3
350	12.725	9.71906	7.28990	9.59197	98.83	1.1844	9.6683	338.948	1.7784	6.0102	1148.3
400	12.400	9.66114	7.24645	9.53480	98.67	1.1786	9.6216	338.755	1.7768	6.0041	1312.3
450	12.075	9.60349	7.20321	9.47791	98.50	1.1729	9.5751	338.562	1.7752	5.9980	1476.4
500	11.750	9.54612+2	7.16018+2	9.42129-1	98.33	1.1673+0	9.5288-1	338.370	1.7737-5	5.9919-6	1640.4
550	11.425	9.48904	7.11736	9.36495	98.17	1.1616	9.4826	338.177	1.7721	5.9858	1804.5
600	11.100	9.43223	7.07475	9.30889	98.00	1.1560	9.4366	337.983	1.7705	5.9796	1968.5
650	10.775	9.37570	7.03235	9.25309	97.84	1.1504	9.3908	337.790	1.7689	5.9735	2132.5
700	10.450	9.31944	6.99015	9.19757	97.67	1.1448	9.3451	337.597	1.7673	5.9674	2296.6
750	10.126	9.26346	6.94816	9.14232	97.50	1.1392	9.2996	337.403	1.7658	5.9612	2460.6
800	9.801	9.20775	6.90638	9.08734	97.34	1.1337	9.2543	337.210	1.7642	5.9551	2624.7
850	9.476	9.15231	6.86480	9.03263	97.17	1.1281	9.2092	337.016	1.7626	5.9490	2788.7
900	9.151	9.09714	6.82342	8.97818	97.00	1.1226	9.1642	336.822	1.7610	5.9428	2952.8
950	8.826	9.04225	6.78225	8.92401	96.84	1.1171	9.1194	336.629	1.7594	5.9367	3116.8
1000	8.501	8.98762+2	6.74127+2	8.87009-1	96.68	1.1117+0	9.0748-1	336.435	1.7579-5	5.9305-6	3280.8
1050	8.176	8.93327	6.70050	8.81645	96.50	1.1062	9.0303	336.240	1.7563	5.9244	3444.9
1100	7.851	8.87918	6.65993	8.76307	96.34	1.1008	8.9860	336.046	1.7547	5.9182	3608.9
1150	7.526	8.82535	6.61956	8.70995	96.18	1.0954	8.9419	335.852	1.7531	5.9121	3773.0
1200	7.201	8.77180	6.57939	8.65709	96.00	1.0900	8.8979	335.657	1.7515	5.9059	3937.0
1250	6.877	8.71850	6.53941	8.60449	95.84	1.0846	8.8541	335.463	1.7499	5.8998	4101.0
1300	6.552	8.66547	6.49964	8.55215	95.68	1.0793	8.8105	335.268	1.7483	5.8936	4265.1
1350	6.227	8.61270	6.46006	8.50008	95.51	1.0740	8.7670	335.074	1.7467	5.8875	4429.1
1400	5.902	8.56020	6.42068	8.44826	95.34	1.0687	8.7237	334.879	1.7451	5.8813	4593.2
1450	5.577	8.50795	6.38149	8.39669	95.18	1.0634	8.6806	334.684	1.7436	5.8752	4757.2
1500	5.252	8.45596+2	6.34249+2	8.34539-1	95.01	1.0581+0	8.6376-1	334.489	1.7420-5	5.8690-6	4921.3
1550	4.927	8.40423	6.30369	8.29433	94.84	1.0529	8.5948	334.293	1.7404	5.8628	5085.3
1600	4.603	8.35276	6.26509	8.24354	94.68	1.0476	8.5521	334.098	1.7388	5.8567	5249.3
1650	4.278	8.30155	6.22667	8.19299	94.51	1.0424	8.5096	333.903	1.7372	5.8505	5413.4
1700	3.953	8.25059	6.18845	8.14270	94.34	1.0372	8.4673	333.707	1.7356	5.8443	5577.4
1750	3.628	8.19988	6.15042	8.09265	94.17	1.0321	8.4252	333.511	1.7340	5.8382	5741.5
1800	3.303	8.14943	6.11258	8.04286	94.01	1.0269	8.3832	333.316	1.7324	5.8320	5905.5
1850	2.978	8.09923	6.07492	7.99332	93.84	1.0218	8.3413	333.120	1.7308	5.8258	6069.6
1900	2.654	8.04928	6.03746	7.94402	93.68	1.0167	8.2996	332.924	1.7292	5.8197	6233.6
1950	2.329	7.99958	6.00018	7.89498	93.51	1.0116	8.2581	332.728	1.7276	5.8135	6397.6
2000	2.004	7.95014+2	5.96309+2	7.84618-1	93.34	1.0066+0	8.2168-1	332.532	1.7260-5	5.8073-6	6561.7
2050	1.679	7.90094	5.92619	7.79762	93.17	1.0015	8.1756	332.335	1.7244	5.8011	6725.7
2100	1.355	7.85199	5.88947	7.74931	93.01	9.9648-1	8.1345	332.139	1.7228	5.7949	6889.8
2150	1.030	7.80328	5.85294	7.70124	92.84	9.9147	8.0936	331.942	1.7212	5.7887	7053.8
2200	0.705	7.75482	5.81659	7.65341	92.67	9.8648	8.0529	331.746	1.7196	5.7826	7217.8
2250	0.380	7.70661	5.78043	7.60583	92.51	9.8151	8.0124	331.549	1.7180	5.7764	7381.9
2300	0.055	7.65863	5.74445	7.55849	92.34	9.7656	7.9719	331.352	1.7164	5.7702	7545.9
2350	-0.269	7.61091	5.70865	7.51138	92.17	9.7163	7.9317	331.155	1.7147	5.7640	7710.0
2400	-0.594	7.56342	5.67303	7.46452	92.01	9.6672	7.8916	330.958	1.7131	5.7578	7874.0
2450	-0.919	7.51618	5.63760	7.41789	91.84	9.6183	7.8517	330.761	1.7115	5.7516	8038.1

* Interpolated by the editors from the table on page 257.

ICAO Standard Atmosphere

Geometric altitude (m)	Temperature (°C)	Atmospheric pressure mbar	Atmospheric pressure torr	p/p_0	Boiling point of water[b] (°C)	Density (kg m⁻³)	ϱ/ϱ_0	Velocity of sound (m s⁻¹)	Dynamic viscosity (N s m⁻²)	Thermal conductivity (kcal m⁻¹ s⁻¹ deg⁻¹)	Geometric altitude (ft)
2500				-1	91 67	9 5695-1	7 8119-1	330 563	1 7099-5	5 7454-6	8202 1
2550					91 51	9 5210	7 7722	330 366	1 7083	5 7392	8366 1
2600					91 34	9 4726	7 7328	330 168	1 7067	5 7330	8530 2
2650					91 17	9 4245	7 6934	329 971	1 7051	5 7268	8694 2
2700					91 01	9 3765	7 6543	329 773	1 7035	5 7206	8858 3
2750					90 84	9 3287	7 6153	329.575	1 7019	5 7144	9022 3
2800					90 67	9 2811	7 5764	329 377	1.7002	5 7082	9186 4
2850					90 50	9 2337	7 5377	329 179	1 6986	5 7019	9350 4
2900					90 33	9 1864	7 4991	328 980	1 6970	5 6957	9514 4
2950					90 17	9 1394	7 4607	328 782	1 6954	5 6895	9678 5
3000						925-1	7 4225-1	328 583	1 6938-5	5 6833-6	9842 5
3050						459	7 3844	328 385	1 6921	5 6771	10006 6
3100						994	7 3464	328 186	1 6905	5 6709	10170 6
3150						531	7.3086	327 987	1 6889	5 6646	10334 6
3200						069	7 2710	327 788	1 6873	5 6584	10498 7
3250						610	7 2335	327 589	1 6857	5 6522	10662 7
3300						152	7 1961	327 390	1 6840	5 6460	10826 8
3350						697	7 1589	327 191	1 6824	5 6397	10990 8
3400						243	7 1219	326 991	1 6808	5 6335	11154 9
3450						791	7 0849	326 792	1 6792	5 6273	11318 9
3500						340-1	7 0482-1	326 592	1 6775-5	5 6210-6	11482 9
3550						892	7 0116	326 392	1 6759	5 6148	11647 0
3600						445	6 9751	326 192	1 6743	5 6085	11811 0
3650						000	6 9388	325 992	1 6726	5 6023	11975 1
3700						557	6 9026	325 792	1 6710	5 5961	12139 1
3750						4115	6 8666	325 592	1 6694	5 5898	12303 1
3800						676	6 8307	325 391	1 6677	5 5836	12467 2
3850						238	6 7949	325 191	1 6661	5 5773	12631 2
3900						802	6 7593	324 990	1 6645	5 5711	12795 3
3950						2367	6 7239	324 790	1 6628	5 5648	12959 3
4000						1935-1	6 6885-1	324 589	1 6612-5	5 5586-6	13123 4
4050						504	6 6534	324 388	1 6596	5 5523	13287 4
4100						1075	6 6183	324 187	1 6579	5 5460	13451 4
4150						647	6 5835	323 985	1 6563	5 5398	13615 5
4200						222	6 5487	323 784	1 6546	5 5335	13779 5
4250						798	6 5141	323 582	1 6530	5 5273	13943 6
4300						376	6 4796	323 381	1 6513	5 5210	14107 6
4350						955	6 4453	323 179	1 6497	5 5147	14271 7
4400						536	6 4111	322 977	1 6481	5 5084	14435 7
4450						119	6 3771	322 775	1 6464	5 5022	14599 7
4500						704-1	6 3432-1	322 573	1 6448-5	5 4959-6	14763 8
4550						290	6 3094	322 371	1 6431	5 4896	14927 8
4600						878	6 2758	322 169	1 6415	5 4833	15091 9
4650						468	6 2423	321 966	1 6398	5 4771	15255 9
4700						059	6 2089	321 764	1 6382	5 4708	15419 9
4750						652	6 1757	321 561	1 6365	5 4645	15584 0
4800						247	6 1426	321 358	1 6349	5 4582	15748 0
4850						4844	6 1097	321 155	1 6332	5 4519	15912 1
4900						442	6 0769	320 952	1 6316	5 4456	16076 1
4950						041	6 0442	320 749	1 6299	5 4393	16240 2
5000						643-1	6 0117-1	320 545	1 6282-5	5 4331-6	16404 2
5050						246	5 9793	320 342	1 6266	5 4268	16568 2
5100						851	5 9470	320 138	1 6249	5 4205	16732 3
5150						457	5 9149	319 935	1 6233	5 4142	16896 3
5200						065	5 8829	319 731	1 6216	5 4079	17060 4
5250						1675	5 8510	319 527	1 6200	5 4016	17224 4
5300						1286	5 8192	319 323	1 6183	5 3953	17388 5
5350						899	5 7876	319 118	1 6166	5 3890	17552 5
5400						513	5 7562	318 914	1 6150	5 3826	17716 5
5450						129	5 7248	318 710	1 6133	5 3763	17880 6
5500						747-1	5 6936-1	318 505	1 6116-5	5 3700-6	18044 6
5550						366	5 6625	318 300	1 6100	5 3637	18208 7
5600						987	5 6316	318 095	1 6083	5 3574	18372 7
5650						610	5 6008	317 890	1 6066	5 3511	18536 7
5700						234	5 5701	317 685	1 6050	5 3448	18700 8
5750						859	5 5395	317 480	1 6033	5 3384	18864 8
5800						486	5 5091	317 275	1 6016	5 3321	19028 9
5850						115	5 4788	317 069	1 6000	5 3258	19192 9
5900						746	5 4486	316 863	1 5983	5 3195	19357 0
5950						378	5 4186	316 658	1 5966	5 3131	19521 0
6000						011-1	5 3887-1	316 452	1 5949-5	5 3068-6	19685 0
6050						646	5 3589	316 246	1 5933	5 3005	19849 1
6100						283	5 3292	316 039	1 5916	5 2941	20013 1
6150						4921	5 2997	315 833	1 5899	5 2878	20177 2
6200						4561	5 2703	315 627	1 5882	5 2815	20341 2
6250						4202	5 2410	315 420	1 5865	5 2751	20505 2
6300						845	5 2118	315 213	1 5849	5 2688	20669 3
6350						489	5 1828	315 007	1 5832	5 2624	20833 3
6400						135	5 1539	314 800	1 5815	5 2561	20997 4
6450						782	5 1251	314 593	1 5798	5 2497	21161 4
6500						431-1	5 0964-1	314 385	1 5781-5	5 2434-6	21325 5
6550						081	5 0679	314 178	1 5764	5 2370	21489 5
6600						733	5 0394	313 970	1 5748	5 2307	21653 5
6650						387	5 0112	313 763	1 5731	5 2243	21817 6
6700						041	4 9830	313 555	1 5714	5 2180	21981 6
6750						698	4 9549	313 347	1 5697	5 2116	22145 7
6800						356	4 9270	313 139	1 5680	5 2052	22309 7
6850						015	4 8992	312 931	1 5663	5 1989	22473 8
6900						676	4 8715	312 723	1 5646	5 1925	22637 8
6950						338	4 8439	312 514	1 5629	5 1862	22801 8
7000						002-1	4 8165-1	312 306	1 5612-5	5 1798-6	22965 9
7050						667	4 7891	312 097	1 5595	5 1734	23129 9
7100						334	4 7619	311 888	1 5578	5 1670	23294 0
7150						4002	4 7348	311 679	1 5561	5 1607	23458 0
7200						671	4 7079	311 470	1 5544	5 1543	23622 0
7250						342	4 6810	311 261	1 5527	5 1479	23786 1
7300						015	4 6543	311 051	1 5510	5 1415	23950 1
7350						689	4 6277	310 842	1 5493	5 1352	24114 2
7400						364	4 6012	310 632	1 5476	5 1288	24278 2
7450						041	4 5748	310 422	1 5459	5 1224	24442 3

[a] Int

Geometric altitude (m)	Temperature (°C)	Atmospheric pressure mbar	Atmospheric pressure torr	p/p_0	Boiling point of water* (°C)	Density (kg m^{-3})	ϱ/ϱ_0	Velocity of sound (m s^{-1})	Dynamic viscosity (N s m^{-2})	Thermal conductivity (kcal m^{-1} s^{-1} deg^{-1})	Geometric altitude (ft)
7500	-33.693	3.82996+2	2.87271+2	3.77988-1	74.84	5.5719-1	4.5485-1	310.212	1.5442-5	5.1160-6	24606.3
7550	-34.017	3.80279	2.85232	3.75306	74.68	5.5399	4.5224	310.002	1.5425	5.1096	24770.3
7600	-34.341	3.77577	2.83206	3.72639	74.51	5.5080	4.4963	309.792	1.5408	5.1032	24934.4
7650	-34.665	3.74890	2.81191	3.69988	74.34	5.4762	4.4704	309.582	1.5391	5.0968	25098.4
7700	-34.989	3.72219	2.79187	3.67352	74.17	5.4446	4.4446	309.371	1.5374	5.0904	25262.5
7750	-35.314	3.69564	2.77196	3.64731	74.00	5.4131	4.4189	309.160	1.5357	5.0840	25426.5
7800	-35.638	3.66924	2.75215	3.62125	73.83	5.3818	4.3933	308.950	1.5340	5.0776	25590.6
7850	-35.962	3.64299	2.73247	3.59535	73.66	5.3506	4.3678	308.739	1.5323	5.0712	25754.6
7900	-36.286	3.61689	2.71289	3.56960	73.49	5.3196	4.3425	308.528	1.5305	5.0648	25918.6
7950	-36.610	3.59095	2.69343	3.54399	73.32	5.2886	4.3173	308.317	1.5288	5.0584	26082.7
8000	-36.935	3.56516+2	2.67409+2	3.51854-1	73.15	5.2579-1	4.2921-1	308.105	1.5271-5	5.0520-6	26246.7
8050	-37.259	3.53952	2.65486	3.49323	72.97	5.2272	4.2671	307.894	1.5254	5.0456	26410.8
8100	-37.583	3.51403	2.63574	3.46807	72.80	5.1967	4.2422	307.682	1.5237	5.0392	26574.8
8150	-37.907	3.48868	2.61673	3.44306	72.63	5.1663	4.2174	307.470	1.5220	5.0328	26738.8
8200	-38.231	3.46349	2.59783	3.41820	72.47	5.1361	4.1927	307.258	1.5202	5.0264	26902.9
8250	-38.555	3.43845	2.57905	3.39348	72.29	5.1060	4.1682	307.046	1.5185	5.0200	27066.9
8300	-38.880	3.41355	2.56037	3.36891	72.12	5.0761	4.1437	306.834	1.5168	5.0135	27231.0
8350	-39.204	3.38880	2.54181	3.34448	71.96	5.0462	4.1194	306.622	1.5151	5.0071	27395.0
8400	-39.528	3.36419	2.52335	3.32020	71.78	5.0165	4.0951	306.409	1.5134	5.0007	27559.1
8450	-39.852	3.33973	2.50500	3.29606	71.62	4.9870	4.0710	306.197	1.5116	4.9943	27723.1
8500	-40.176	3.31541+2	2.48677+2	3.27206-1	71.44	4.9576-1	4.0470-1	305.984	1.5099-5	4.9878-6	27887.1
8600	-40.824	3.26721	2.45061	3.22449	71.11	4.8991	3.9993	305.558	1.5065	4.9750	28215.2
8700	-41.473	3.21958	2.41489	3.17748	70.76	4.8412	3.9520	305.131	1.5030	4.9621	28543.3
8800	-42.121	3.17252	2.37959	3.13103	70.42	4.7838	3.9052	304.704	1.4995	4.9493	28871.4
8900	-42.769	3.12602	2.34470	3.08514	70.08	4.7270	3.8588	304.276	1.4961	4.9364	29199.5
9000	-43.417	3.08007+2	2.31024+2	3.03979-1	69.73	4.6706-1	3.8128-1	303.848	1.4926-5	4.9235-6	29527.6
9100	-44.065	3.03467	2.27619	2.99498	69.39	4.6148	3.7672	303.419	1.4891	4.9106	29855.6
9200	-44.714	2.98981	2.24254	2.95071	69.05	4.5595	3.7220	302.989	1.4856	4.8977	30183.7
9300	-45.362	2.94550	2.20930	2.90698	68.70	4.5047	3.6773	302.559	1.4822	4.8848	30511.8
9400	-46.010	2.90172	2.17647	2.86377	68.37	4.4504	3.6330	302.129	1.4787	4.8719	30839.9
9500	-46.658	2.85846+2	2.14402+2	2.82109-1	68.02	4.3966-1	3.5891-1	301.697	1.4752-5	4.8590-6	31168.0
9600	-47.306	2.81574	2.11198	2.77892	67.68	4.3433	3.5456	301.265	1.4717	4.8460	31496.1
9700	-47.954	2.77353	2.08032	2.73726	67.33	4.2905	3.5025	300.833	1.4682	4.8331	31824.1
9800	-48.602	2.73184	2.04905	2.69612	66.99	4.2382	3.4598	300.400	1.4647	4.8201	32152.2
9900	-49.250	2.69066	2.01816	2.65548	66.65	4.1864	3.4175	299.966	1.4612	4.8072	32480.3
10000	-49.898	2.64999+2	1.98765+2	2.61533-1	66.30	4.1351-1	3.3756-1	299.532	1.4577-5	4.7942-6	32808.4
10100	-50.546	2.60981	1.95752	2.57568	65.96	4.0843	3.3341	299.097	1.4541	4.7813	33136.5
10200	-51.194	2.57013	1.92776	2.53652	65.61	4.0339	3.2930	298.661	1.4506	4.7683	33464.6
10300	-51.842	2.53094	1.89836	2.49785	65.27	3.9840	3.2523	298.225	1.4471	4.7553	33792.7
10400	-52.490	2.49224	1.86934	2.45965	64.92	3.9346	3.2119	297.788	1.4436	4.7423	34120.7
10500	-53.137	2.45402	1.84067	2.42193	64.58	3.8857	3.1720	297.350	1.4400	4.7293	34448.8
10600	-53.785	2.41628	1.81236	2.38468	64.24	3.8372	3.1324	296.912	1.4365	4.7163	34776.9
10700	-54.433	2.37901	1.78441	2.34790	63.89	3.7892	3.0933	296.474	1.4329	4.7033	35105.0
10800	-55.081	2.34221	1.75680	2.31158	63.55	3.7417	3.0545	296.034	1.4294	4.6903	35433.1
10900	-55.729	2.30587	1.72955	2.27572	63.20	3.6946	3.0160	295.594	1.4258	4.6772	35761.2
11000	-56.376	2.26999+2	1.70263+2	2.24031-1	62.85	3.6480-1	2.9780-1	295.154	1.4223-5	4.6642-6	36089.2
11100	-56.500	2.23460	1.67609	2.20538	62.51	3.5932	2.9332	295.069	1.4216	4.6617	36417.3
11200	-56.500	2.19976	1.64996	2.17100	62.16	3.5372	2.8875	295.069	1.4216	4.6617	36745.4
11300	-56.500	2.16547	1.62423	2.13715	61.82	3.4820	2.8425	295.069	1.4216	4.6617	37073.5
11400	-56.500	2.13171	1.59891	2.10383	61.47	3.4277	2.7982	295.069	1.4216	4.6617	37401.6
11500	-56.500	2.09848	1.57399	2.07103	61.14	3.3743	2.7545	295.069	1.4216	4.6617	37729.7
11600	-56.500	2.06576	1.54945	2.03875	60.79	3.3217	2.7116	295.069	1.4216	4.6617	38057.7
11700	-56.500	2.03356	1.52530	2.00697	60.45	3.2699	2.6693	295.069	1.4216	4.6617	38385.8
11800	-56.500	2.00186	1.50152	1.97568	60.11	3.2189	2.6277	295.069	1.4216	4.6617	38713.9
11900	-56.500	1.97066	1.47812	1.94489	59.77	3.1688	2.5868	295.069	1.4216	4.6617	39042.0
12000	-56.500	1.93994+2	1.45508+2	1.91457-1	59.44	3.1194-1	2.5464-1	295.069	1.4216-5	4.6617-6	39370.1
12100	-56.500	1.90970	1.43240	1.88473	59.10	3.0708	2.5067	295.069	1.4216	4.6617	39698.2
12200	-56.500	1.87994	1.41007	1.85536	58.76	3.0229	2.4677	295.069	1.4216	4.6617	40026.2
12300	-56.500	1.85064	1.38809	1.82644	58.42	2.9758	2.4292	295.069	1.4216	4.6617	40354.3
12400	-56.500	1.82180	1.36646	1.79797	58.09	2.9294	2.3914	295.069	1.4216	4.6617	40682.4
12500	-56.500	1.79341	1.34517	1.76995	57.75	2.8838	2.3541	295.069	1.4216	4.6617	41010.5
12600	-56.500	1.76546	1.32420	1.74237	57.42	2.8388	2.3174	295.069	1.4216	4.6617	41338.6
12700	-56.500	1.73795	1.30357	1.71522	57.09	2.7946	2.2813	295.069	1.4216	4.6617	41666.7
12800	-56.500	1.71086	1.28325	1.68849	56.75	2.7510	2.2457	295.069	1.4216	4.6617	41994.8
12900	-56.500	1.68420	1.26326	1.66218	56.42	2.7082	2.2107	295.069	1.4216	4.6617	42322.8
13000	-56.500	1.65796+2	1.24357+2	1.63628-1	56.09	2.6660-1	2.1763-1	295.069	1.4216-5	4.6617-6	42650.9
13100	-56.500	1.63213	1.22420	1.61078	55.76	2.6244	2.1424	295.069	1.4216	4.6617	42979.0
13200	-56.500	1.60670	1.20512	1.58569	55.43	2.5835	2.1090	295.069	1.4216	4.6617	43307.1
13300	-56.500	1.58166	1.18634	1.56098	55.10	2.5433	2.0761	295.069	1.4216	4.6617	43635.2
13400	-56.500	1.55702	1.16786	1.53666	54.77	2.5037	2.0438	295.069	1.4216	4.6617	43963.3
13500	-56.500	1.53276	1.14967	1.51272	54.45	2.4646	2.0120	295.069	1.4216	4.6617	44291.3
13600	-56.500	1.50888	1.13176	1.48915	54.12	2.4262	1.9806	295.069	1.4216	4.6617	44619.4
13700	-56.500	1.48538	1.11412	1.46595	53.80	2.3884	1.9498	295.069	1.4216	4.6617	44947.5
13800	-56.500	1.46224	1.09677	1.44312	53.48	2.3512	1.9194	295.069	1.4216	4.6617	45275.6
13900	-56.500	1.43946	1.07968	1.42063	53.15	2.3146	1.8895	295.069	1.4216	4.6617	45603.7
14000	-56.500	1.41704+2	1.06286+2	1.39851-1	52.83	2.2786-1	1.8600-1	295.069	1.4216-5	4.6617-6	45931.8
14500	-56.500	1.31006	9.82628+1	1.29293	51.22	2.1065	1.7196	295.069	1.4216	4.6617	47572.2
15000	-56.500	1.21118	9.08460	1.19534	49.63	1.9475	1.5898	295.069	1.4216	4.6617	49212.6
15500	-56.500	1.11978	8.39901	1.10513	48.07	1.8006	1.4699	295.069	1.4216	4.6617	50853.0
16000	-56.500	1.03528	7.76525	1.02174	46.51	1.6647	1.3589	295.069	1.4216	4.6617	52493.4
16500	-56.500	9.57175+1	7.17940	9.44658-2	44.98	1.5391	1.2564	295.069	1.4216	4.6617	54133.9
17000	-56.500	8.84971	6.63783	8.73399	43.47	1.4230	1.1616	295.069	1.4216	4.6617	55774.3
17500	-56.500	8.18225	6.13719	8.07525	41.96	1.3157	1.0740	295.069	1.4216	4.6617	57414.7
18000	-56.500	7.56522	5.67438	7.46629	40.41	1.2165	9.9304-2	295.069	1.4216	4.6617	59055.1
18500	-56.500	6.99481	5.24654	6.90334	39.01	1.1247	9.1816	295.069	1.4216	4.6617	60695.5
19000	-56.500	6.46748+1	4.85101+1	6.38291-2	37.56	1.0400-1	8.4894-2	295.069	1.4216-5	4.6617-6	62336.0
19500	-56.500	5.97998	4.48536	5.90179	36.13	9.6157-2	7.8495	295.069	1.4216	4.6617	63976.4
20000	-56.500	5.52930	4.14732	5.45700	34.70	8.8910	7.2579	295.069	1.4216	4.6617	65616.8
21000	-55.569	4.72893	3.54699	4.66709	31.92	7.5715	6.1808	295.703	1.4267	4.6804	68897.6
22000	-54.576	4.04749	3.03587	3.99456	29.19	6.4510	5.2661	296.377	1.4322	4.7004	72178.5
23000	-53.583	3.46686	2.60036	3.42153	26.53	5.5006	4.4903	297.049	1.4376	4.7204	75459.3
24000	-52.590	2.97174	2.22899	2.93288	23.94	4.6938	3.8317	297.720	1.4430	4.7403	78740.2
25000	-51.598	2.54922	1.91207	2.51588	21.42	4.0084	3.2722	298.389	1.4484	4.7602	82021.0
26000	-50.606	2.18837	1.64141	2.15976	18.94	3.4257	2.7965	299.056	1.4538	4.7800	85301.8
27000	-49.614	1.87997	1.41009	1.85539	16.54	2.9298	2.3917	299.722	1.4592	4.7999	88582.7
28000	-48.623	1.61619+1	1.21225+1	1.59506-2	14.18	2.5076-2	2.0470-2	300.386	1.4646-5	4.8197-6	91863.5
29000	-47.632	1.39042	1.04290	1.37224	11.87	2.1478	1.7533	301.048	1.4699	4.8395	95144.4
30000	-46.641	1.19703	8.97846+0	1.18138	9.63	1.8410	1.5029	301.709	1.4753	4.8593	98425.2
31000	-45.650	1.03126	7.73508	1.01777	7.43	1.5792	1.2891	302.368	1.4806	4.8790	101706.0
32000	-44.660	8.89063+0	6.66852	8.77437-3	5.26	1.3555	1.1065	303.025	1.4859	4.8988	104986.9

* Interpolated by the editors from the table on page 257.

The correction factor f_t is calculated from the formula $f_t = 1 - \frac{(\beta - \alpha)\,t}{1 + \beta t}$
where

Brass scale

Barometer temperature *t* °C	600	610	620	630	640	650	660	670	680	690	700	710	720	730	740	750	760	770	780	790	Correction factor f_t
	Barometer reading β_t in mm Hg — Amount Δ_t in millimetres to be subtracted																				
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0 999 837
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	999 673
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	999 520
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40	3 89	3 96	4 02	4 09	4 15	4 22	4 28	4 35	4 41	4 48	4 54	4 61	4 67	4 74	4 80	4 87	4 93	5 00	5 06	5 13	0 993 511

Glass scale

Barometer temperature *t* °C	600	610	620	630	640	650	660	670	680	690	700	710	720	730	740	750	760	770	780	790	Correction factor f_t
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0 999 827
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4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	999 307
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24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	995 859
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0 995 687
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	995 515
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	995 344
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	995 170
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	995 001
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0 994 829
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	994 658
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	994 487
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	994 315
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	994 144
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0 993 974
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	993 802
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	993 631
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	993 460
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	993 289
40	4 13	4 20	4 27	4 34	4 40	4 47	4 54	4 61	4 68	4 75	4 82	4 89	4 96	5 02	5 09	5 16	5 23	5 30	5 37	5 44	0 993 118

Saturation pressure of water vapour below 0 °C over ice

microbar (µb) [1]

°C	9	8	7	6	5	4	3	2	1	0
-90	0.017	0.021	0.026	0.031	0.038	0.046	0.055	0.067	0.080	0.097
-80	0.116	0.139	0.166	0.198	0.235	0.280	0.332	0.393	0.464	0.547
-70	0.644	0.758	0.889	1.042	1.220	1.425	1.662	1.936	2.252	2.615
-60	3.032	3.511	4.060	4.688	5.406	6.225	7.159	8.223	9.432	10.80
-50	12.36	14.13	16.12	18.38	20.92	23.80	27.03	30.67	34.76	39.35
-40	44.49	50.26	56.71	63.93	71.98	80.97	90.98	102.1	114.5	128.3
-30	143.6	160.6	179.4	200.2	223.3	248.8	276.9	307.9	342.1	379.8

0.001 torr*

°C	9	8	7	6	5	4	3	2	1	0
-90	0.013	0.016	0.019	0.023	0.028	0.034	0.042	0.050	0.060	0.07
-80	0.087	0.104	0.124	0.148	0.176	0.210	0.249	0.294	0.348	0.41
-70	0.483	0.568	0.667	0.782	0.915	1.07	1.25	1.45	1.69	1.96
-60	2.27	2.63	3.05	3.52	4.05	4.67	5.37	6.17	7.07	8.10
-50	9.27	10.60	12.09	13.79	15.69	17.85	20.27	23.00	26.07	29.51
-40	33.37	37.70	42.54	47.95	53.99	60.73	68.24	76.58	85.88	96.23
-30	107.7	120.5	134.6	150.2	167.5	186.6	207.7	230.9	256.6	284.9

millibar (mb) [1]

°C	.9	.8	.7	.6	.5	.4	.3	.2	.1	.0
-29	0.384	0.388	0.392	0.396	0.400	0.404	0.408	0.413	0.417	0.421
-28	0.426	0.430	0.435	0.439	0.444	0.448	0.453	0.457	0.462	0.467
-27	0.472	0.477	0.481	0.486	0.491	0.496	0.501	0.507	0.512	0.517
-26	0.522	0.528	0.533	0.538	0.544	0.549	0.555	0.561	0.566	0.572
-25	0.578	0.584	0.590	0.596	0.602	0.608	0.614	0.620	0.626	0.632
-24	0.639	0.645	0.652	0.658	0.665	0.671	0.678	0.685	0.692	0.699
-23	0.706	0.713	0.720	0.727	0.734	0.741	0.749	0.756	0.763	0.771
-22	0.779	0.786	0.794	0.802	0.810	0.818	0.826	0.834	0.842	0.850
-21	0.859	0.867	0.875	0.884	0.893	0.901	0.910	0.919	0.928	0.937
-20	0.946	0.955	0.965	0.974	0.983	0.993	1.002	1.012	1.022	1.032
-19	1.042	1.052	1.062	1.072	1.082	1.092	1.103	1.114	1.124	1.135
-18	1.146	1.157	1.168	1.179	1.190	1.201	1.213	1.225	1.236	1.248
-17	1.260	1.272	1.284	1.296	1.308	1.320	1.333	1.345	1.358	1.371
-16	1.384	1.397	1.410	1.424	1.437	1.451	1.464	1.478	1.492	1.506
-15	1.520	1.534	1.548	1.562	1.577	1.592	1.607	1.622	1.637	1.652
-14	1.667	1.683	1.698	1.714	1.730	1.746	1.762	1.778	1.795	1.811
-13	1.827	1.844	1.861	1.878	1.895	1.913	1.930	1.948	1.966	1.984
-12	2.002	2.020	2.039	2.057	2.076	2.095	2.114	2.133	2.153	2.172
-11	2.191	2.211	2.231	2.251	2.271	2.292	2.313	2.334	2.355	2.376
-10	2.397	2.419	2.440	2.462	2.484	2.506	2.529	2.551	2.574	2.597
- 9	2.620	2.644	2.667	2.691	2.715	2.739	2.763	2.787	2.812	2.837
- 8	2.862	2.888	2.913	2.939	2.965	2.991	3.017	3.043	3.070	3.097
- 7	3.124	3.152	3.180	3.208	3.236	3.264	3.292	3.321	3.350	3.379
- 6	3.409	3.438	3.468	3.499	3.529	3.560	3.591	3.622	3.653	3.685
- 5	3.717	3.748	3.781	3.813	3.846	3.879	3.913	3.947	3.981	4.015
- 4	4.049	4.084	4.119	4.154	4.190	4.226	4.262	4.298	4.335	4.372
- 3	4.409	4.447	4.485	4.523	4.561	4.600	4.638	4.678	4.717	4.757
- 2	4.797	4.838	4.878	4.920	4.961	5.003	5.045	5.087	5.130	5.173
- 1	5.217	5.260	5.305	5.349	5.394	5.439	5.485	5.530	5.577	5.623
0	5.670	5.717	5.764	5.812	5.860	5.909	5.958	6.007	6.057	6.107

torr*

°C	.9	.8	.7	.6	.5	.4	.3	.2	.1	.0
-29	0.288	0.291	0.294	0.297	0.300	0.303	0.306	0.310	0.313	0.316
-28	0.319	0.323	0.326	0.329	0.333	0.336	0.340	0.343	0.347	0.350
-27	0.354	0.357	0.361	0.365	0.369	0.372	0.376	0.380	0.384	0.388
-26	0.392	0.396	0.400	0.404	0.408	0.412	0.416	0.421	0.425	0.430
-25	0.433	0.438	0.442	0.447	0.451	0.456	0.460	0.465	0.470	0.474
-24	0.479	0.484	0.489	0.494	0.499	0.504	0.509	0.514	0.519	0.524
-23	0.529	0.534	0.540	0.545	0.551	0.556	0.561	0.567	0.573	0.578
-22	0.584	0.590	0.596	0.601	0.607	0.613	0.619	0.625	0.632	0.638
-21	0.644	0.650	0.657	0.663	0.670	0.676	0.683	0.689	0.696	0.703
-20	0.710	0.717	0.723	0.731	0.738	0.745	0.752	0.759	0.767	0.774
-19	0.782	0.789	0.797	0.804	0.812	0.819	0.827	0.836	0.843	0.851
-18	0.860	0.868	0.876	0.884	0.893	0.901	0.910	0.919	0.927	0.936
-17	0.945	0.954	0.963	0.972	0.981	0.990	1.000	1.009	1.019	1.028
-16	1.038	1.048	1.058	1.068	1.078	1.088	1.098	1.109	1.119	1.130
-15	1.140	1.151	1.161	1.172	1.183	1.194	1.205	1.217	1.228	1.239
-14	1.250	1.262	1.274	1.286	1.298	1.310	1.322	1.334	1.346	1.358
-13	1.370	1.383	1.396	1.409	1.421	1.435	1.448	1.461	1.475	1.488
-12	1.502	1.515	1.529	1.543	1.557	1.571	1.586	1.600	1.615	1.629
-11	1.643	1.658	1.673	1.688	1.703	1.719	1.735	1.751	1.766	1.782
-10	1.798	1.814	1.830	1.847	1.863	1.880	1.897	1.913	1.931	1.948
- 9	1.965	1.983	2.000	2.018	2.036	2.054	2.072	2.090	2.109	2.128
- 8	2.147	2.166	2.185	2.204	2.224	2.243	2.263	2.282	2.303	2.323
- 7	2.343	2.364	2.385	2.406	2.427	2.448	2.469	2.491	2.513	2.534
- 6	2.557	2.579	2.601	2.624	2.647	2.670	2.693	2.717	2.740	2.764
- 5	2.788	2.811	2.836	2.860	2.885	2.909	2.935	2.960	2.986	3.011
- 4	3.037	3.063	3.090	3.116	3.143	3.170	3.197	3.224	3.252	3.279
- 3	3.307	3.336	3.364	3.393	3.421	3.450	3.479	3.509	3.538	3.568
- 2	3.598	3.629	3.659	3.690	3.721	3.753	3.784	3.816	3.848	3.880
- 1	3.913	3.945	3.979	4.012	4.046	4.080	4.114	4.148	4.183	4.218
0	4.253	4.288	4.323	4.359	4.395	4.432	4.469	4.506	4.543	4.581

Saturation pressure of water vapour below 0 °C over water

millibar (mb) [1]

°C	.9	.8	.7	.6	.5	.4	.3	.2	.1	.0
-14	1.928	1.944	1.960	1.976	1.992	2.009	2.025	2.042	2.059	2.076
-13	2.093	2.110	2.127	2.144	2.162	2.180	2.197	2.215	2.233	2.252
-12	2.270	2.288	2.307	2.326	2.345	2.364	2.383	2.402	2.421	2.441
-11	2.461	2.480	2.500	2.521	2.541	2.561	2.582	2.602	2.623	2.644
-10	2.666	2.687	2.708	2.730	2.752	2.774	2.796	2.818	2.840	2.863
- 9	2.885	2.908	2.931	2.954	2.978	3.001	3.025	3.049	3.073	3.097
- 8	3.121	3.146	3.171	3.196	3.221	3.246	3.271	3.297	3.323	3.348
- 7	3.375	3.401	3.427	3.454	3.481	3.508	3.535	3.562	3.590	3.618
- 6	3.646	3.674	3.702	3.731	3.759	3.788	3.818	3.847	3.876	3.906
- 5	3.936	3.966	3.997	4.027	4.058	4.089	4.120	4.151	4.183	4.215
- 4	4.247	4.279	4.312	4.344	4.377	4.410	4.444	4.477	4.511	4.545
- 3	4.579	4.614	4.649	4.684	4.719	4.754	4.790	4.826	4.862	4.898
- 2	4.935	4.972	5.009	5.046	5.084	5.121	5.160	5.198	5.236	5.275
- 1	5.314	5.354	5.393	5.433	5.473	5.514	5.554	5.595	5.637	5.678
0	5.720	5.762	5.804	5.847	5.889	5.933	5.976	6.020	6.064	6.108

torr*

°C	.9	.8	.7	.6	.5	.4	.3	.2	.1	.0
-14	1.446	1.458	1.470	1.482	1.494	1.507	1.519	1.532	1.544	1.557
-13	1.570	1.582	1.595	1.608	1.622	1.635	1.648	1.662	1.675	1.689
-12	1.703	1.716	1.730	1.744	1.759	1.773	1.787	1.802	1.816	1.831
-11	1.846	1.861	1.876	1.891	1.906	1.921	1.936	1.952	1.968	1.983
-10	1.999	2.015	2.031	2.048	2.064	2.080	2.097	2.114	2.130	2.147
- 9	2.164	2.181	2.199	2.216	2.234	2.251	2.269	2.287	2.305	2.323
- 8	2.341	2.360	2.378	2.397	2.416	2.435	2.454	2.473	2.492	2.512
- 7	2.531	2.551	2.571	2.591	2.611	2.631	2.651	2.672	2.693	2.714
- 6	2.734	2.756	2.777	2.798	2.820	2.842	2.863	2.885	2.908	2.930
- 5	2.952	2.975	2.998	3.021	3.044	3.067	3.090	3.114	3.138	3.161
- 4	3.185	3.210	3.234	3.259	3.283	3.308	3.333	3.358	3.384	3.409
- 3	3.435	3.461	3.487	3.513	3.539	3.566	3.593	3.620	3.647	3.674
- 2	3.701	3.729	3.757	3.785	3.813	3.841	3.870	3.899	3.928	3.957
- 1	3.986	4.016	4.045	4.075	4.105	4.136	4.166	4.197	4.228	4.259
0	4.290	4.322	4.353	4.385	4.417	4.450	4.482	4.515	4.548	4.581

Saturation pressure of water vapour above 100 °C

bar (b)*

°C	0	1	2	3	4	5	6	7	8	9
100	1.0133	1.0499	1.0877	1.1267	1.1667	1.2080	1.2505	1.2940	1.3391	1.3851
110	1.4326	1.4815	1.5315	1.5831	1.6362	1.6905	1.7464	1.8038	1.8628	1.9234
120	1.9854	2.0489	2.1146	2.1816	2.2502	2.3211	2.3933	2.4676	2.5436	2.6216
130	2.7013	2.7830	2.8670	2.9526	3.0408	3.1294	3.2215	3.3173	3.4139	3.5128
140	3.614	3.718	3.823	3.931	4.042	4.155	4.271	4.389	4.510	4.635
150	4.760	4.889	5.022	5.155	5.293	5.434	5.578	5.724	5.873	6.026
160	6.181	6.340	6.502	6.666	6.835	7.008	7.182	7.361	7.544	7.730
170	7.921	8.113	8.311	8.510	8.717	8.925	9.136	9.353	9.573	9.798
180	10.026	10.258	10.495	10.736	10.982	11.231	11.487	11.746	12.009	12.277
190	12.550	12.826	13.107	13.395	13.686	13.984	14.286	14.592	14.905	15.222
200	15.544	15.873	16.206	16.543	16.887	17.237	17.595	17.956	18.322	18.695
210	19.072	19.458	19.850	20.245	20.649	21.055	21.471	21.892	22.321	22.755
220	23.192	23.640	24.095	24.555	25.020	25.495	25.975	26.463	26.958	27.460
230	27.969	28.484	29.007	29.536	30.075	30.621	31.175	31.734	32.303	32.879
240	33.465	34.055	34.656	35.263	35.880	36.505	37.138	37.778	38.429	39.086
250	39.754	40.429	41.114	41.806	42.510	43.220	43.940	44.670	45.409	46.155
260	46.913	47.678	48.454	49.239	50.035	50.840	51.652	52.478	53.311	54.155
270	55.010	55.876	56.750	57.635	58.531	59.436	60.354	61.280	62.221	63.171
280	64.134	65.106	66.088	67.083	68.091	69.112	70.143	71.188	72.244	73.313
290	74.39	75.48	76.59	77.71	78.84	79.99	81.14	82.32	83.49	84.70
300	85.90	87.13	88.37	89.61	90.87	92.14	93.42	94.73	96.06	97.36
310	98.69	100.05	101.43	102.81	104.21	105.63	107.05	108.49	109.95	111.42
320	112.91	114.42	115.94	117.48	119.03	120.59	122.17	123.76	125.38	127.02
330	128.67	130.33	132.02	133.72	135.43	137.16	138.92	140.69	142.48	144.29
340	146.11	147.94	149.80	151.65	153.56	155.47	157.42	159.36	161.34	163.33
350	165.32	167.35	169.39	171.45	173.53	175.63	177.75	179.91	182.09	184.29
360	186.51	188.75	191.02	193.31	195.63	198.01	200.41	202.82	205.26	207.74
370	210.24	212.76	215.33	217.94	220.60	(← critical temperature)				

atmosphere (atm) [2]

°C	0	1	2	3	4	5	6	7	8	9
100	1.0000	1.0362	1.0735	1.1120	1.1514	1.1922	1.2341	1.2771	1.3216	1.3670
110	1.4139	1.4621	1.5115	1.5624	1.6148	1.6684	1.7236	1.7802	1.8384	[illegible]
120	1.9594	2.0221	2.0869	2.1531	2.2208	2.2907	2.3620	2.4353	2.5103	2.5873
130	2.6660	2.7466	2.8295	2.9140	3.0010	3.0885	3.1794	3.2739	3.3693	3.4669
140	3.567	3.669	3.773	3.880	3.989	4.101	4.215	4.332	4.451	4.574
150	4.698	4.825	4.956	5.088	5.224	5.363	5.505	5.649	5.796	5.947
160	6.100	6.257	6.417	6.579	6.746	6.916	7.088	7.265	7.445	7.629
170	7.817	8.007	8.202	8.399	8.603	8.808	9.017	9.231	9.448	9.670
180	9.895	10.124	10.358	10.596	10.838	11.084	11.337	11.592	11.852	12.116
190	12.386	12.658	12.936	13.220	13.507	13.801	14.099	14.401	14.710	15.023
200	15.341	15.665	15.994	16.327	16.666	17.012	17.365	17.721	18.082	18.451
210	18.823	19.204	19.590	19.980	20.379	20.780	21.190	21.606	22.029	22.457
220	22.889	23.331	23.780	24.234	24.693	25.162	25.635	26.117	26.605	27.101
230	27.603	28.112	28.628	29.150	29.682	30.221	30.767	31.319	31.881	32.449
240	33.027	33.610	34.203	34.802	35.411	36.028	36.652	37.284	37.926	38.575
250	39.234	39.900	40.5					[illegible]	44.815	45.551
260	46.300	47.055	47.8							
270	54.291	55.145	56.0							
280	63.295	64.255	65.2							
290	73.42	74.49	75.5	[illegible]	[illegible]	[illegible]				
300	84.78	85.99	87.21	88.44	89.68	90.94	92.20	93.49	94.80	[illegible]
310	97.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105.65	107.07	108.51	[illegible]
320	111.[illegible]						120.57	122.14	123.74	[illegible]
330	126.[illegible]						137.10	138.85	140.62	142.43
340	144.[illegible]						155.36	157.28	159.23	161.19
350	163.16	165.16	167.17	169.21	171.26	173.33	175.43	177.56	179.71	[illegible]
360	184.07	186.28	188.52	190.78	193.07	195.42	197.79	200.17	202.58	205.02
370	207.49	209.98	212.51	215.09	217.72	(← critical temperature)				

[1] Values from *Smithsonian Meteorological Tables*, Smithsonian Institution, [illegible] (D.C.) 1966.

[2] Values from KEYES, F.G., *Int.crit.Tab.*, 3, 233 (1928).

* Values calculated by the editors of these *Scientific Tables*.

Vapour Pressure and Boiling Point of Water

Saturation pressure in millibar †

°C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	6.11	6.15	6.20	6.24	6.29	6.33	6.38	6.43	6.47	6.52
1	6.57	6.61	6.66	6.71	6.76	6.81	6.86	6.90	6.95	7.00
2	7.05	7.11	7.16	7.21	7.26	7.31	7.36	7.42	7.47	7.52
3	7.58	7.63	7.68	7.74	7.79	7.85	7.90	7.96	8.02	8.07
4	8.13	8.19	8.24	8.30	8.36	8.42	8.48	8.54	8.60	8.66
5	8.72	8.78	8.84	8.90	8.97	9.03	9.09	9.15	9.22	9.28
6	9.35	9.41	9.48	9.54	9.61	9.67	9.74	9.81	9.88	9.94
7	10.01	10.08	10.15	10.22	10.29	10.36	10.43	10.51	10.58	10.65
8	10.72	10.80	10.87	10.94	11.02	11.09	11.17	11.24	11.32	11.40
9	11.47	11.55	11.63	11.71	11.79	11.87	11.95	12.03	12.11	12.19
10	12.27	12.36	12.44	12.52	12.61	12.69	12.78	12.86	12.95	13.03
11	13.12	13.21	13.30	13.38	13.47	13.56	13.65	13.74	13.83	13.93
12	14.02	14.11	14.20	14.30	14.39	14.49	14.58	14.68	14.77	14.87
13	14.97	15.07	15.17	15.27	15.37	15.47	15.57	15.67	15.77	15.87
14	15.98	16.08	16.19	16.29	16.40	16.50	16.61	16.72	16.83	16.94
15	17.04	17.15	17.26	17.38	17.49	17.60	17.71	17.83	17.94	18.06
16	18.17	18.29	18.41	18.52	18.64	18.76	18.88	19.00	19.12	19.25
17	19.37	19.49	19.61	19.74	19.86	19.99	20.12	20.24	20.37	20.50
18	20.63	20.76	20.89	21.02	21.16	21.29	21.42	21.56	21.69	21.83
19	21.96	22.10	22.24	22.38	22.52	22.66	22.80	22.94	23.09	23.23
20	23.37	23.52	23.66	23.81	23.96	24.11	24.26	24.41	24.56	24.71
21	24.86	25.01	25.17	25.32	25.48	25.64	25.79	25.95	26.11	26.27
22	26.43	26.59	26.75	26.92	27.08	27.25	27.41	27.58	27.75	27.92
23	28.09	28.26	28.43	28.60	28.77	28.95	29.12	29.30	29.48	29.65
24	29.83	30.01	30.19	30.37	30.56	30.74	30.92	31.11	31.30	31.48
25	31.67	31.86	32.05	32.24	32.43	32.63	32.82	33.02	33.21	33.41
26	33.61	33.81	34.01	34.21	34.41	34.62	34.82	35.03	35.23	35.44
27	35.65	35.86	36.07	36.28	36.50	36.71	36.92	37.14	37.36	37.58
28	37.80	38.02	38.24	38.46	38.69	38.91	39.14	39.37	39.59	39.82
29	40.06	40.29	40.52	40.76	40.99	41.23	41.47	41.71	41.95	42.19
30	42.43	42.67	42.92	43.17	43.41	43.66	43.91	44.17	44.42	44.67
31	44.93	45.18	45.44	45.70	45.96	46.22	46.49	46.75	47.02	47.28
32	47.55	47.82	48.09	48.36	48.64	48.91	49.19	49.47	49.75	50.03
33	50.31	50.59	50.87	51.16	51.45	51.74	52.03	52.32	52.61	52.90
34	53.20	53.50	53.80	54.10	54.40	54.70	55.00	55.31	55.62	55.93
35	56.24	56.55	56.86	57.18	57.49	57.81	58.13	58.45	58.77	59.10
36	59.42	59.75	60.08	60.41	60.74	61.07	61.41	61.74	62.08	62.42
37	62.76	63.11	63.45	63.80	64.14	64.49	64.84	65.20	65.55	65.91
38	66.26	66.62	66.99	67.35	67.71	68.08	68.45	68.82	69.19	69.56
39	69.93	70.31	70.69	71.07	71.45	71.83	72.22	72.61	72.99	73.39
40	73.78	74.17	74.57	74.97	75.37	75.77	76.17	76.58	76.98	77.39
41	77.80	78.22	78.63	79.05	79.47	79.89	80.31	80.73	81.16	81.59
42	82.02	82.45	82.88	83.32	83.75	84.19	84.64	85.08	85.53	85.97
43	86.42	86.88	87.33	87.79	88.24	88.70	89.17	89.63	90.10	90.56
44	91.03	91.51	91.98	92.46	92.94	93.42	93.90	94.39	94.87	95.36
45	95.86	96.35	96.85	97.34	97.84	98.35	98.85	99.36	99.87	100.38
46	100.89	101.41	101.93	102.45	102.97	103.50	104.03	104.56	105.09	105.62
47	106.16	106.70	107.24	107.78	108.33	108.88	109.43	109.98	110.54	111.10
48	111.66	112.22	112.79	113.36	113.93	114.50	115.07	115.65	116.23	116.81
49	117.40	117.99	118.58	119.17	119.77	120.37	120.97	121.57	122.18	122.79
50	123.40	124.01	124.63	125.25	125.87	126.49	127.12	127.75	128.38	129.01
51	129.65	130.29	130.93	131.58	132.23	132.88	133.53	134.19	134.84	135.51
52	136.17	136.84	137.51	138.18	138.86	139.54	140.22	140.91	141.60	142.29
53	142.98	143.68	144.38	145.08	145.78	146.49	147.20	147.91	148.63	149.35
54	150.07	150.80	151.53	152.26	152.99	153.73	154.47	155.21	155.96	156.71
55	157.46	158.22	158.97	159.74	160.50	161.27	162.04	162.82	163.59	164.38
56	165.16	165.95	166.74	167.53	168.33	169.13	169.93	170.74	171.55	172.36
57	173.18	174.00	174.82	175.65	176.48	177.31	178.15	178.99	179.83	180.68
58	181.53	182.38	183.24	184.10	184.96	185.83	186.70	187.58	188.45	189.34
59	190.22	191.11	192.00	192.89	193.79	194.69	195.60	196.51	197.42	198.34
60	199.26	200.18	201.11	202.05	202.98	203.92	204.86	205.81	206.76	207.71
61	208.67	209.63	210.59	211.56	212.53	213.51	214.49	215.48	216.46	217.45
62	218.45	219.45	220.45	221.46	222.47	223.48	224.50	225.52	226.54	227.58
63	228.61	229.65	230.70	231.74	232.79	233.85	234.91	235.97	237.03	238.11
64	239.18	240.26	241.34	242.43	243.52	244.62	245.72	246.82	247.93	249.04
65	250.16	251.28	252.41	253.54	254.67	255.81	256.95	258.10	259.25	260.40
66	261.56	262.73	263.90	265.07	266.25	267.43	268.61	269.80	271.00	272.20
67	273.40	274.61	275.82	277.04	278.26	279.49	280.72	281.96	283.20	284.45
68	285.70	286.96	288.21	289.48	290.75	292.02	293.30	294.58	295.86	297.15
69	298.45	299.75	301.06	302.37	303.69	305.01	306.34	307.67	309.00	310.34
70	311.69	313.04	314.39	315.75	317.12	318.49	319.87	321.25	322.63	324.02
71	325.42	326.82	328.22	329.63	331.05	332.47	333.89	335.33	336.76	338.20
72	339.65	341.10	342.56	344.03	345.50	346.97	348.45	349.93	351.42	352.91
73	354.41	355.91	357.43	358.94	360.46	361.99	363.52	365.06	366.61	368.15
74	369.71	371.27	372.84	374.41	375.99	377.57	379.16	380.75	382.35	383.95
75	385.56	387.18	388.80	390.43	392.06	393.70	395.34	396.99	398.65	400.31
76	401.98	403.65	405.34	407.02	408.71	410.41	412.11	413.82	415.53	417.25
77	418.98	420.71	422.45	424.20	425.95	427.71	429.47	431.24	433.02	434.80
78	436.59	438.38	440.18	441.99	443.80	445.62	447.45	449.28	451.11	452.96
79	454.81	456.67	458.53	460.40	462.28	464.16	466.05	467.94	469.85	471.76
80	473.67	475.59	477.52	479.45	481.39	483.34	485.29	487.25	489.22	491.19
81	493.17	495.16	497.15	499.16	501.17	503.18	505.20	507.23	509.26	511.30
82	513.35	515.41	517.47	519.54	521.62	523.70	525.79	527.89	529.99	532.10
83	534.22	536.35	538.48	540.62	542.77	544.92	547.08	549.25	551.43	553.61
84	555.80	557.99	560.20	562.41	564.62	566.85	569.08	571.32	573.57	575.83
85	578.09	580.36	582.64	584.93	587.22	589.52	591.83	594.14	596.46	598.79
86	601.13	603.48	605.83	608.19	610.56	612.94	615.32	617.72	620.12	622.52
87	624.94	627.36	629.79	632.23	634.68	637.13	639.59	642.07	644.55	647.03
88	649.53	652.03	654.54	657.06	659.59	662.12	664.66	667.22	669.78	672.34
89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	687.92	690.55	693.18	695.82	698.47
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	714.55	717.26	719.98	722.71	725.45
91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	747.64	750.46	753.28
92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	776.18	779.09	782.00
93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	805.62	808.61	811.62
94	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	835.99	839.08	842.17
95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	867.30	870.48	873.68
96	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	899.57	902.86	906.15
97	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	932.84	936.23	939.62
98	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	967.12	970.61	974.10
99	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1002.45	1006.04	1009.64
100	1013.25									

Boiling point in degree Celsius *

mbar	0	1	2	3	4	5	6	7	8	9
0		-16.52	-12.90	-8.35	-5.02	-2.40	-0.21	+1.90	3.78	5.46
10	6.99	8.38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	17.52	18.29								
30	24.10	24.65								
40	28.99	29.41								
50	32.90	33.26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	36.19	36.49								
70	39.03	39.29								
80	41.54	41.77								
90	43.79	44.00								
100	45.84	46.03	46.23	46.42	46.61	46.79	46.98	47.17	47.35	47.53
110	47.72	47.89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49.23
120	49.45	49.62								50.91
130	51.07	51.22								52.43
140	52.58	52.72								53.85
150	54.00	54.14	54.28	54.41	54.55	54.68	54.82	54.95	55.08	55.21
160	55.35	55.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	56.49
170	56.62	56.74								
180	57.93	57.98								
190	58.99	59.10								
200	60.09	60.20								
210	61.15	61.25								
220	62.17	62.26								
230	63.14	63.24								
240	64.09	64.18								
250	64.99	65.08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
260	65.87	65.96								
270	66.72	66.81								
280	67.55	67.63								
290	68.35	68.43								
300	69.13	69.20								
310	69.88	69.96								
320	70.62	70.69								
330	71.33	71.40								
340	72.03	72.10								
350	72.71	72.78								
360	73.38	73.44								
370	74.02	74.09								
380	74.66	74.72								
390	75.28	75.34								
400	75.89	75.95								
410	76.48	76.54								
420	77.06	77.12								
430	77.63	77.69								
440	78.19	78.25								
450	78.74	78.80								
460	79.28	79.34								
470	79.81	79.86								
480	80.33	80.38								
490	80.84	80.89	80.94	81.00	81.05	81.09	81.15	[illegible]	[illegible]	
500	81.35	81.40	81.45	81.49	81.54	81.59	81.64	81.69	81.74	81.79
510	81.84	81.89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	82.18	82.23	[illegible]
520	82.33	82.37								
530	82.80	82.85								
540	83.27	83.32								
550	83.74	83.78								
560	84.19	84.24								
570	84.64	84.69								
580	85.09	85.13								
590	85.52	85.57								
600	85.95	86.00								
610	86.38	86.42								
620	86.80	86.84								
630	87.21	87.25								
640	87.62	87.66								
650	88.02	88.06								
660	88.42	88.46								
670	88.81	88.85								
680	89.20	89.23								
690	89.58	89.62								
700	89.96	90.00								
710	90.33	90.37								
720	90.70	90.74								
730	91.06	91.10								
740	91.43	91.46								
750	91.78	91.82	91.85	91.89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
760	92.14	92.17	92.21	92.24	92.28	92.31	92.35	92.38	[illegible]	[illegible]
770	92.48	92.52	92.55	92.59	92.62	92.66	92.69	92.73	92.76	[illegible]
780	92.83	92.86	92.90	92.93	92.97	93.00	93.04	93.07	93.10	93.14
790	93.17	93.20	93.24	93.27	93.31	93.34	93.37	93.41	93.44	93.48
800	93.51	93.54	93.58	93.61	93.64	93.68	93.71	93.74	93.78	93.81
810	93.84	93.88	93.91	93.94	93.98	94.01	94.04	94.08	94.11	94.14
820	94.18	94.21	94.24	94.27	94.31	94.34	94.37	94.41	94.44	[illegible]
830	94.50	94.54	94.57	94.60	94.63	94.67	94.70	94.73	94.76	[illegible]
840	94.83	94.86	94.89	94.92	94.96	94.99	95.02	95.05	95.09	95.12
850	95.15	95.18	95.21	95.24	95.28	95.31	95.34	95.37	95.40	95.44
860	95.47	95.50	95.53	95.56	95.59	95.62	95.66	95.69	95.72	[illegible]
870	95.78	95.81	95.85	95.88	95.91	95.94	95.97	96.00	96.03	[illegible]
880	96.09	96.13	96.16	96.19	96.22	96.25	96.28	96.31	96.34	[illegible]
890	96.40	96.43	96.47	96.50	96.53	96.56	96.59	96.62	96.65	[illegible]
900	96.71	96.74	96.77	96.80	96.83	96.86	96.89	96.92	96.95	[illegible]
910	97.01	97.04	97.07	97.10	97.13	97.16	97.19	97.22	97.25	[illegible]
920	97.32	97.34	97.37	97.40	97.43	97.46	97.49	97.52	97.55	[illegible]
930	97.61	97.64	97.67	97.70	97.73	97.76	97.79	97.82	97.85	[illegible]
940	97.91	97.94	97.97	98.00	98.03	98.06	98.08	98.11	98.14	[illegible]
950	98.20	98.23	98.26	98.29	98.32	98.35	98.38	98.40	98.43	[illegible]
960	98.49	98.52	98.55	98.58	98.61	98.64	98.66	98.69	98.72	[illegible]
970	98.78	98.81					[illegible]	98.98	99.01	[illegible]
980	99.06	99.09						99.26	99.29	[illegible]
990	99.35	99.37						99.54	99.57	[illegible]
1000	99.63									

† Values from *Smithsonian Meteorological Tables*, Smithsonian Institution, Washington, D.C., 1966.

e table gives factors for conversion of spirometer
s to lung values calculated from the formula

$$\frac{(p - p_{t\,H_2O})(1 + 37\alpha)}{(p - p_{37°\,H_2O})(1 + t\,\alpha)}$$

where p = measured pressure of the spirometer volume (mm Hg)

t = measured temperature of the spirometer volume (°C)

$p_{t\,H_2O}$ and $p_{37°\,H_2O}$ = pressure of water vapour at the measured temperature of the spirometer volume and at 37 °C in the lungs respectively

α = volume coefficient of expansion of air per °C (see page 260)

p / t	490	500	510	520	530	540	550	560	570	580	590	600	610	620	630
0	1 2447	1 2423	1 2400	1 2378	1 2357	1 2337	1 2317	1 2299	1 2281	1 2263	1 2247	1 2231	1 2215	1 2200	1 2186
1	2393	2369	2347	2325	2304	2284	2265	2246	2228	2211	2195	2179	2164	2149	2134
2	2339	2315	2293	2271	2250	2231	2212	2193	2176	2159	2143	2127	2112	2097	2083
3	2284	2261	2239	2217	2197	2177	2159	2141	2123	2107	2091	2075	2060	2046	2032
4	2229	2206	2184	2163	2143	2124	2105	2088	2071	2054	2038	2023	2008	1994	1980
5	1 2174	1 2151	1 2130	1 2109	1 2089	1 2070	1 2052	1 2034	1 2018	1 2001	1 1986	1 1971	1 1956	1 1942	1 1929
6	2118	2096	2075	2054	2035	2016	1998	1981	1964	1948	1933	1918	1904	1890	1877
7	2062	2041	2020	2000	1980	1962	1944	1927	1911	1895	1880	1866	1852	1838	1825
8	2006	1985	1964	1944	1926	1907	1890	1873	1857	1842	1827	1813	1799	1786	1773
9	1949	1928	1908	1889	1870	1853	1836	1819	1803	1788	1774	1760	1746	1733	1720
10	1 1892	1 1872	1 1852	1 1833	1 1815	1 1797	1 1781	1 1764	1 1749	1 1734	1 1720	1 1706	1 1693	1 1680	1 1667
11	1835	1814	1795	1776	1759	1742	1725	1709	1694	1680	1666	1652	1639	1627	1614
12	1777	1757	1738	1720	1702	1685	1669	1654	1639	1625	1611	1598	1585	1573	1561
13	1718	1698	1680	1662	1645	1629	1613	1598	1584	1570	1556	1543	1531	1519	1507
14	1658	1640	1622	1604	1588	1572	1556	1542	1528	1514	1501	1488	1476	1464	1453
15	1 1598	1 1580	1 1562	1.1546	1 1529	1 1514	1 1499	1 1485	1 1471	1 1458	1 1445	1 1433	1 1421	1 1409	1 1398
16	1538	1520	1503	1486	1471	1456	1441	1427	1414	1401	1389	1377	1365	1354	1343
17	1476	1459	1442	1426	1411	1397	1383	1369	1356	1344	1332	1320	1309	1298	1288
18	1414	1397	1381	1366	1351	1337	1323	1310	1298	1286	1274	1263	1252	1242	1232
19	1351	1335	1319	1304	1290	1276	1263	1251	1239	1227	1216	1205	1195	1184	1175
20	1 1287	1 1271	1 1256	1 1242	1 1228	1 1215	1 1203	1 1191	1 1179	1 1168	1 1157	1 1146	1 1136	1 1127	1 1117
21	1221	1207	1193	1179	1166	1153	1141	1129	1118	1108	1097	1087	1078	1068	1059
22	1156	1141	1128	1115	1102	1090	1079	1068	1057	1047	1037	1027	1018	1009	1001
23	1089	1075	1062	1050	1038	1026	1015	1005	0995	0985	0975	0966	0958	0949	0941
24	1020	1008	0995	0983	0972	0961	0951	0941	0931	0922	0913	0905	0896	0888	0881
25	1 0951	1 0939	1 0927	1 0916	1 0906	1 0895	1 0886	1 0876	1 0867	1 0859	1 0850	1 0842	1 0834	1 0827	1 0819
26	0880	0869	0858	0848	0838	0828	0819	0810	0802	0794	0786	0778	0771	0764	0757
27	0808	0798	0788	0778	0769	0760	0752	0744	0736	0728	0721	0714	0707	0701	0694
28	0735	0725	0716	0707	0699	0691	0683	0675	0668	0661	0655	0648	0642	0636	0630
29	0660	0651	0643	0635	0627	0620	0613	0606	0600	0593	0587	0581	0576	0570	0565
30	1 0584	1 0576	1 0568	1 0561	1 0554	1 0548	1 0542	1 0536	1 0530	1 0524	1 0519	1 0514	1 0509	1 0504	1 0499
31	0506	0499	0492	0486	0480	0474	0469	0464	0459	0454	0449	0444	0440	0436	0432
32	0426	0420	0415	0409	0404	0399	0395	0390	0386	0382	0378	0374	0370	0367	0363
33	0345	0340	0335	0331	0327	0323	0319	0315	0312	0309	0305	0302	0299	0296	0293
34	0261	0258	0254	0251	0248	0245	0242	0239	0236	0234	0231	0229	0227	0224	0222
35	1 0176	1 0174	1 0171	1 0169	1 0167	1 0165	1 0163	1 0161	1 0159	1 0157	1 0156	1 0154	1 0153	1 0151	1 0150
36	0089	0088	0087	0086	0084	0083	0082	0081	0081	0080	0079	0078	0077	0076	0076

p / t	640	650	660	670	680	690	700	710	720	730	740	750	760	770	780
0	1 2172	1 2158	1 2145	1 2133	1 2120	1 2109	1 2097	1 2086	1 2075	1 2065	1 2054	1 2045	1 2035	1 2025	1 2016
1	2121	2107	2094	2082	2070	2058	2047	2036	2025	2015	2005	1995	1985	1976	1967
2	2070	2056	2044	2031	2019	2008	1997	1986	1975	1965	1955	1945	1936	1927	1918
3	2018	2005	1993	1981	1969	1957	1946	1936	1925	1915	1905	1896	1886	1877	1869
4	1967	1954	1942	1930	1918	1907	1896	1885	1875	1865	1855	1846	1837	1828	1819
5	1 1916	1 1903	1 1891	1 1879	1 1867	1 1856	1 1846	1 1835	1 1825	1 1815	1 1806	1 1796	1 1787	1 1778	1 1770
6	1864	1852	1840	1828	1817	1806	1795	1785	1775	1765	1756	1746	1738	1729	1721
7	1812	1800	1788	1777	1765	1755	1744	1734	1724	1715	1706	1697	1688	1679	1671
8	1760	1748	1736	1725	1714	1704	1693	1683	1674	1664	1655	1647	1638	1630	1621
9	1708	1696	1685	1674	1663	1652	1642	1633	1623	1614	1605	1596	1588	1580	1572
10	1 1655	1 1644	1 1633	1 1622	1 1611	1 1601	1 1591	1 1582	1 1572	1 1563	1 1554	1 1546	1 1538	1 1530	1 1522
11	1603	1591	1580	1570	1559	1549	1540	1530	1521	1512	1504	1495	1487	1479	1472
12	1549	1538	1528	1517	1507	1497	1488	1479	1470	1461	1453	1444	1437	1429	1421
13	1496	1485	1475	1464	1455	1445	1436	1427	1418	1410	1401	1393	1386	1378	1371
14	1442	1431	1421	1411	1402	1392	1383	1375	1366	1358	1350	1342	1334	1327	1320
15	1 1388	1 1377	1 1367	1 1358	1 1348	1 1339	1 1331	1 1322	1 1314	1 1306	1 1298	1 1290	1 1283	1 1276	1 1269
16	1333	1323	1313	1304	1295	1286	1277	1269	1261	1253	1246	1238	1231	1224	1217
17	1278	1268	1258	1249	1241	1232	1224	1216	1208	1200	1193	1186	1179	1172	1166
18	1222	1212	1203	1194	1186	1178	1170	1162	1154	1147	1140	1133	1126	1120	1113
19	1165	1156	1147	1139	1131	1123	1115	1108	1100	1093	1086	1080	1073	1067	1061
20	1 1108	1 1100	1 1091	1 1083	1 1075	1 1067	1 1060	1 1053	1 1046	1 1039	1 1032	1 1026	1 1020	1 1014	1 1008
21	1051	1042	1034	1026	1019	1011	1004	0997	0991	0984	0978	0972	0966	0960	0954
22	0992	0984	0976	0969	0962	0955	0948	0941	0935	0929	0923	0917	0911	0905	0900
23	0933	0926	0918	0911	0904	0897	0891	0885	0879	0873	0867	0861	0856	0851	0845
24	0873	0866	0859	0852	0846	0839	0833	0827	0822	0816	0810	0805	0800	0795	0790
25	1 0812	1 0806	1 0799	1 0793	1 0787	1 0781	1 0775	1 0769	1 0764	1 0759	1 0753	1 0748	1 0744	1 0739	1 0734
26	0751	0744	0739	0732	0727	0721	0716	0710	0705	0700	0696	0691	0686	0682	0678
27	0688	0682	0677	0671	0666	0661	0656	0651	0646	0642	0637	0633	0629	0625	0621
28	0625	0619	0614	0609	0604	0599	0595	0590	0586	0582	0578	0574	0570	0566	0563
29	0560	0555	0551	0546	0542	0537	0533	0529	0525	0521	0518	0514	0511	0507	0504
30	1 0495	1 0490	1 0486	1 0482	1 0478	1 0474	1 0470	1 0467	1 0463	1 0460	1 0457	1 0453	1 0450	1 0447	1 0444
31	0428	0424	0420	0417	0413	0410	0407	0403	0400	0397	0395	0392	0389	0386	0384
32	0360	0357	0353	0350	0347	0345	0342	0339	0337	0334	0332	0329	0327	0325	0322
33	0291	0288	0285	0283	0280	0278	0276	0274	0272	0270	0268	0266	0264	0262	0260
34	0220	0218	0216	0214	0212	0211	0209	0207	0206	0204	0202	0201	0199	0198	0197
35	1 0149	1 0147	1 0145	1 0144	1 0143	1 0142	1 0141	1 0139	1 0138	1 0137	1 0136	1 0135	1 0134	1 0133	1 0132
36	0075	0074	0073	0073	0072	0072	0071	0070	0070	0069	0069	0068	0068	0067	0067

Reduction of Gas Volumes*

The following remarks are applicable to any other gas in place of air without appreciable error (see under 'Basis of calculation', below).

Explanation of the tables

mm Hg Values in the uppermost line of each table = observed pressure in mm Hg of the measured gas volume. Under many conditions of measurement this will be the same as the ambient (atmospheric) pressure, i.e., the observed barometric pressure after correction for temperature. Correction for pressure of water vapour under conditions of saturation is also provided for in the table (see under '*sat.*' below).

°C Values in the extreme left-hand column = observed temperature of the measured gas volume.

dry Factor for the reduction of the measured volume of *dry* gas to *normal conditions* (0 °C, 760 mm Hg, dry). Normal gas volumes are indicated by the abbreviation NTP (normal temperature and pressure). American lung specialists have introduced the abbreviation STPD (standard temperature and pressure, dry).

sat. Factor for the reduction of the measured volume of gas *saturated with water vapour* to normal conditions (0 °C, 760 mm Hg, dry). Gases may be assumed to be saturated with water vapour if they are in contact with water. This applies to the air in the lungs and to exhaled air, as also to spirometer air (if not dried). For the pressure of saturated water vapour at various temperatures see pages 256–258.

Use of the tables

A. Reduction of measured gas volumes to normal conditions (NTP)

The measured volume is multiplied by the factor appropriate to the conditions of measurement (temperature, pressure, dry or saturated).

Examples: 1. What is the volume at NTP of 1.6 l of dry gas measured at 25 °C and 712 mm Hg? Required volume at NTP = 1.6 × 0.8581 = 1.3730 l (NTP).

2. What is the volume at NTP of 1.6 l of gas saturated with water vapour and measured at 25 °C and 712 mm Hg? Required volume at NTP = 1.6 × 0.8295 = 1.3272 l (NTP). This is the type of calculation required to convert spirometer values to NTP.

B. Conversion of measured volumes to other conditions

The measured volume is multiplied by the appropriate conversion facto NTP and the resulting value divided by the conversion factor correspon to the required conditions (temperature, pressure, dry or moist).

Examples: 1. What will be the volume occupied by 1.6 l of gas meas at 25 °C and 730 mm Hg in contact with water when warmed at cons pressure to 37 °C? Required volume = 1.6 × 0.8512/0.7912 = 1.7213 l. Th the type of calculation required to convert spirometer values to lung val The expression BTPS (body temperature and pressure, saturated) is quently used to indicate gas volumes under lung conditions, i.e., 37 °C, at spheric pressure, saturated with water vapour. For direct conversion fact for spirometer to lung values see page 259.

2. What will be the volume occupied by 1.6 l of dry gas measured at 0 °C a 600 mm Hg after saturation with water vapour, warming to 25 °C and co pression to 760 mm Hg? Required volume = 1.6 × 0.7895/0.8873 = 1.423

Basis of calculation

The conversion factors have been calculated on the basis of the followi formulae:

Conversion factor for reduction of *dry* gas volumes to normal $= \dfrac{p}{760\,(1+\alpha\,t)}$, Conversion factor for reduction of *saturated* gas volumes to normal $= \dfrac{p - p_{H_2O}}{760\,(1+\alpha\,t)}$, whe

p, t pressure in mm Hg and temperature in °C of the measured gas volu

p_{H_2O} pressure of saturated water vapour at the temperature t (see pag 256–258).

α volume coefficient of thermal expansion of the gas between 0 and 100 °C at a constant pressure of 760 mm Hg. In these tables the value for ai 0.003670 per °C (Regnault, 1842), has been used. Under the same co ditions the value for an ideal gas is 0.003661 (= 1/273.15), for nitroge 0.003671, for carbon monoxide 0.003669, for carbon dioxide 0.00372 for acetylene 0.003739. The conversion factors are therefore clearl applicable without sensible error to other gases in addition to air.

Note that in calculating the factors the 4th decimal place has been obtaine by rounding off upwards or downwards. Any discrepancies with factors give in other tables (e.g., in the *Handbook of Chemistry and Physics*) are due to th use of other values for the expansion coefficient or conversion factors

mm Hg	600		601		602		603		604		605		606		607		608		609	
°C	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*
0	0.7895	*0.7834*	0.7908	*0.7848*	0.7921	*0.7861*	0.7934	*0.7874*	0.7947	*0.7887*	0.7961	*0.7900*	0.7974	*0.7913*	0.7987	*0.7927*	0.8000	*0.7940*	0.8013	[illegible]
1	7866	*7801*	7879	*7814*	7892	*7828*	7905	*7841*	7918	*7854*	7931	*7867*	7945	*7880*	7958	*7893*	7971	*7906*	7984	[illegible]
2	7837	*7768*	7850	*7781*	7863	*7794*	7876	*7807*	7889	*7820*	7903	*7833*	7916	*7846*	7929	*7859*	7942	*7873*	7955	[illegible]
3	7809	*7735*	7822	*7748*	7835	*7761*	7848	*7774*	7861	*7787*	7874	*7800*	7887	*7813*	7900	*7826*	7913	*7839*	7926	[illegible]
4	7781	*7701*	7793	*7714*	7806	*7727*	7819	*7740*	7832	*7753*	7845	*7766*	7858	*7779*	7871	*7792*	7884	*7805*	7897	[illegible]
5	0.7752	*0.7668*	0.7765	*0.7681*	0.7778	*0.7694*	0.7791	*0.7707*	0.7804	*0.7720*	0.7817	*0.7733*	0.7830	*0.7745*	0.7843	*0.7758*	0.7856	*0.7771*	0.7869	[illegible]
6	7725	*7634*	7738	*7647*	7750	*7660*	7763	*7673*	7776	*7686*	7789	*7699*	7802	*7712*	7815	*7724*	7828	*7737*	7841	[illegible]
7	7697	*7601*	7710	*7613*	7723	*7626*	7735	*7639*	7748	*7652*	7761	*7665*	7774	*7678*	7787	*7690*	7800	*7703*	7812	[illegible]
8	7670	*7567*	7682	*7580*	7695	*7592*	7708	*7605*	7721	*7618*	7733	*7631*	7746	*7643*	7759	*7656*	7772	*7669*	7785	[illegible]
9	7642	*7533*	7655	*7545*	7668	*7558*	7681	*7571*	7693	*7584*	7706	*7596*	7719	*7609*	7731	*7622*	7744	*7635*	7757	[illegible]
10	0.7615	*0.7498*	0.7628	*0.7511*	0.7641	*0.7524*	0.7653	*0.7536*	0.7666	*0.7549*	0.7679	*0.7562*	0.7691	*0.7575*	0.7704	*0.7587*	0.7717	*0.7600*	0.7729	[illegible]
11	7588	*7464*	7601	*7477*	7614	*7489*	7626	*7502*	7639	*7514*	7652	*7527*	7664	*7540*	7677	*7552*	7690	*7565*	7702	[illegible]
12	7562	*7429*	7574	*7442*	7587	*7454*	7600	*7467*	7612	*7480*	7625	*7492*	7637	*7505*	7650	*7517*	7663	*7530*	7675	[illegible]
13	7535	*7394*	7548	*7407*	7560	*7419*	7573	*7432*	7585	*7444*	7598	*7457*	7611	*7470*	7623	*7482*	7636	*7495*	7648	[illegible]
14	7509	*7359*	7521	*7371*	7534	*7384*	7546	*7396*	7559	*7409*	7572	*7421*	7584	*7434*	7597	*7447*	7609	*7459*	7622	[illegible]
15	0.7483	*0.7323*	0.7495	*0.7336*	0.7508	*0.7348*	0.7520	*0.7361*	0.7533	*0.7373*	0.7545	*0.7386*	0.7558	*0.7398*	0.7570	*0.7411*	0.7583	*0.7423*	0.7595	[illegible]
16	7457	*7287*	7469	*7300*	7482	*7312*	7494	*7325*	7507	*7337*	7519	*7350*	7531	*7362*	7544	*7374*	7556	*7387*	7569	[illegible]
17	7431	*7251*	7443	*7264*	7456	*7276*	7468	*7288*	7481	*7301*	7493	*7313*	7505	*7325*	7518	*7338*	7530	*7350*	7543	[illegible]
18	7406	*7215*	7418	*7227*	7430	*7239*	7443	*7252*	7455	*7264*	7467	*7276*	7480	*7289*	7492	*7301*	7504	*7313*	7517	[illegible]
19	7380	*7177*	7392	*7190*	7405	*7202*	7417	*7214*	7429	*7227*	7442	*7239*	7454	*7251*	7466	*7264*	7479	*7276*	7491	[illegible]
20	0.7355	*0.7140*	0.7367	*0.7152*	0.7379	*0.7164*	0.7392	*0.7177*	0.7404	*0.7189*	0.7416	*0.7201*	0.7428	*0.7213*	0.7441	*0.7226*	0.7453	*0.7238*	0.7465	[illegible]
21	7330	*7102*	7342	*7114*	7354	*7126*	7366	*7139*	7379	*7151*	7391	*7163*	7403	*7175*	7415	*7188*	7428	*7200*	7440	[illegible]
22	7305	*7064*	7317	*7076*	7329	*7088*	7341	*7100*	7354	*7112*	7366	*7124*	7378	*7137*	7390	*7149*	7402	*7161*	7415	[illegible]
23	7280	*7025*	7292	*7037*	7304	*7049*	7317	*7061*	7329	*7073*	7341	*7085*	7353	*7097*	7365	*7110*	7377	*7122*	7389	[illegible]
24	7256	*6985*	7268	*6997*	7280	*7009*	7292	*7021*	7304	*7033*	7316	*7046*	7328	*7058*	7340	*7070*	7352	*7082*	7364	[illegible]
25	0.7231	*0.6945*	0.7243	*0.6957*	0.7255	*0.6969*	0.7267	*0.6981*	0.7279	*0.6993*	0.7292	*0.7005*	0.7304	*0.7017*	0.7316	*0.7029*	0.7328	*0.7041*	0.7340	[illegible]
26	7207	*6904*	7219	*6916*	7231	*6928*	7243	*6940*	7255	*6952*	7267	*6964*	7279	*6976*	7291	*6988*	7303	*7000*	7315	[illegible]
27	7183	*6863*	7195	*6875*	7207	*6887*	7219	*6899*	7231	*6911*	7243	*6923*	7255	*6935*	7267	*6947*	7279	*6959*	7291	[illegible]
28	7159	*6821*	7171	*6833*	7183	*6845*	7195	*6857*	7207	*6869*	7219	*6880*	7231	*6892*	7243	*6904*	7255	*6916*	7266	[illegible]
29	7135	*6778*	7147	*6790*	7159	*6802*	7171	*6814*	7183	*6826*	7195	*6838*	7207	*6849*	7219	*6861*	7230	*6873*	7242	[illegible]
30	0.7112	*0.6735*	0.7124	*0.6746*	0.7135	*0.6758*	0.7147	*0.6770*	0.7159	*0.6782*	0.7171	*0.6794*	0.7183	*0.6806*	0.7195	*0.6817*	0.7207	*0.6829*	0.7218	[illegible]
31	7088	*6690*	7100	*6702*	7112	*6714*	7124	*6726*	7136	*6737*	7147	*6749*	7159	*6761*	7171	*6773*	7183	*6785*	7195	[illegible]
32	7065	*6645*	7077	*6657*	7089	*6669*	7100	*6680*	7112	*6692*	7124	*6704*	7136	*6716*	7147	*6728*	7159	*6739*	7171	[illegible]
33	7042	*6599*	7054	*6611*	7065	*6623*	7077	*6634*	7089	*6646*	7101	*6658*	7112	*6670*	7124	*6681*	7136	*6693*	7148	[illegible]
34	7019	*6552*	7031	*6564*	7042	*6576*	7054	*6587*	7066	*6599*	7077	*6611*	7089	*6622*	7101	*6634*	7113	*6646*	7124	[illegible]
35	0.6996	*0.6504*	0.7008	*0.6516*	0.7019	*0.6528*	0.7031	*0.6539*	0.7043	*0.6551*	0.7054	*0.6563*	0.7066	*0.6574*	0.7078	*0.6586*	0.7089	*0.6598*	0.7101	[illegible]
36	6973	*6455*	6985	*6467*	6997	*6479*	7008	*6490*	7020	*6502*	7032	*6514*	7043	*6525*	7055	*6537*	7066	*6548*	7078	[illegible]
37	6951	*6406*	6962	*6417*	6974	*6429*	6986	*6440*	6997	*6452*	7009	*6464*	7020	*6475*	7032	*6487*	7044	*6498*	7055	[illegible]
38	6928	*6355*	6940	*6366*	6952	*6378*	6963	*6389*	6975	*6401*	6986	*6412*	6998	*6424*	7009	*6436*	7021	*6447*	7032	[illegible]
39	6906	*6303*	6918	*6314*	6929	*6326*	6941	*6337*	6952	*6349*	6964	*6360*	6975	*6372*	6987	*6383*	6998	*6395*	7010	[illegible]
40	0.6884	*0.6249*	0.6896	*0.6261*	0.6907	*0.6272*	0.6919	*0.6284*	0.6930	*0.6295*	0.6942	*0.6307*	0.6953	*0.6318*	0.6964	*0.6330*	0.6976	*0.6341*	0.6987	[illegible]
41	6862	*6195*	6874	*6206*	6885	*6218*	6896	*6229*	6908	*6241*	6919	*6252*	6931	*6264*	6942	*6275*	6954	*6286*	6965	[illegible]
42	6840	*6139*	6852	*6151*	6863	*6162*	6875	*6173*	6886	*6185*	6897	*6196*	6909	*6208*	6920	*6219*	6932	*6230*	6943	[illegible]

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Reduction of Gas Volumes

mm Hg	630		631		632		633		634		635		636		637		638		639	
°C	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*
0	0.8289	*0.8229*	0.8303	*0.8242*	0.8316	*0.8256*	0.8329	*0.8269*	0.8342	*0.8282*	0.8355	*0.8295*	0.8368	*0.8308*	0.8382	*0.8321*	0.8395	*0.8334*	0.8408	*0.8343*
1	8259	*8195*	8272	*8208*	8285	*8221*	8298	*8234*	8312	*8247*	8325	*8260*	8338	*8273*	8351	*8286*	8364	*8299*	8377	*8312*
2	8229	*8160*	8242	*8173*	8255	*8186*	8268	*8199*	8281	*8212*	8294	*8225*	8307	*8238*	8321	*8251*	8334	*8264*	8347	*8277*
3	8199	*8125*	8212	*8138*	8225	*8151*	8238	*8164*	8251	*8177*	8264	*8190*	8277	*8203*	8290	*8216*	8303	*8229*	8316	*8242*
4	8170	*8090*	8183	*8103*	8195	*8116*	8208	*8129*	8221	*8142*	8234	*8155*	8247	*8168*	8260	*8181*	8273	*8194*	8286	*8207*
5	0.8140	*0.8056*	0.8153	*0.8068*	0.8166	*0.8081*	0.8179	*0.8094*	0.8192	*0.8107*	0.8205	*0.8120*	0.8218	*0.8133*	0.8231	*0.8146*	0.8243	*0.8159*	0.8256	*0.8172*
6	8111	*8021*	8124	*8033*	8137	*8046*	8149	*8059*	8162	*8072*	8175	*8085*	8188	*8098*	8201	*8111*	8214	*8124*	8227	*8137*
7	8082	*7985*	8095	*7998*	8108	*8011*	8120	*8024*	8133	*8037*	8146	*8050*	8159	*8062*	8172	*8075*	8184	*8088*	8197	*8101*
8	8053	*7950*	8066	*7963*	8079	*7976*	8091	*7989*	8104	*8001*	8117	*8014*	8130	*8027*	8143	*8040*	8155	*8052*	8168	*8065*
9	8024	*7915*	8037	*7928*	8050	*7940*	8063	*7953*	8075	*7966*	8088	*7978*	8101	*7991*	8114	*8004*	8126	*8017*	8139	*8029*
10	0.7996	*0.7879*	0.8009	*0.7892*	0.8021	*0.7905*	0.8034	*0.7917*	0.8047	*0.7930*	0.8059	*0.7943*	0.8072	*0.7955*	0.8085	*0.7968*	0.8098	*0.7981*	0.8110	*0.7993*
11	7968	*7843*	7980	*7856*	7993	*7869*	8006	*7881*	8018	*7894*	8031	*7907*	8044	*7919*	8056	*7932*	8069	*7944*	8082	*7957*
12	7940	*7807*	7952	*7820*	7965	*7832*	7978	*7845*	7990	*7858*	8003	*7870*	8015	*7883*	8028	*7895*	8041	*7908*	8053	*7921*
13	7912	*7771*	7925	*7784*	7937	*7796*	7950	*7809*	7962	*7821*	7975	*7834*	7987	*7846*	8000	*7859*	8012	*7871*	8025	*7884*
14	7884	*7734*	7897	*7747*	7909	*7759*	7922	*7772*	7934	*7784*	7947	*7797*	7959	*7809*	7972	*7822*	7984	*7834*	7997	*7847*
15	0.7857	*0.7697*	0.7869	*0.7710*	0.7882	*0.7722*	0.7894	*0.7735*	0.7907	*0.7747*	0.7919	*0.7760*	0.7932	*0.7772*	0.7944	*0.7785*	0.7957	*0.7797*	0.7969	*0.7810*
16	7830	*7660*	7842	*7673*	7855	*7685*	7867	*7698*	7879	*7710*	7892	*7722*	7904	*7735*	7917	*7747*	7929	*7760*	7942	*7772*
17	7803	*7623*	7815	*7635*	7827	*7647*	7840	*7660*	7852	*7672*	7865	*7685*	7877	*7697*	7889	*7709*	7902	*7722*	7914	*7734*
18	7776	*7585*	7788	*7597*	7800	*7609*	7813	*7622*	7825	*7634*	7838	*7646*	7850	*7659*	7862	*7671*	7875	*7684*	7887	*7696*
19	7749	*7546*	7761	*7559*	7774	*7571*	7786	*7583*	7798	*7596*	7811	*7608*	7823	*7620*	7835	*7633*	7848	*7645*	7860	*7657*
20	0.7723	*0.7508*	0.7735	*0.7520*	0.7747	*0.7532*	0.7759	*0.7544*	0.7772	*0.7557*	0.7784	*0.7569*	0.7796	*0.7581*	0.7808	*0.7593*	0.7821	*0.7606*	0.7833	*0.7618*
21	7696	*7468*	7709	*7481*	7721	*7493*	7733	*7505*	7745	*7517*	7757	*7530*	7770	*7542*	7782	*7554*	7794	*7566*	7806	*7578*
22	7670	*7429*	7682	*7441*	7695	*7453*	7707	*7465*	7719	*7477*	7731	*7490*	7743	*7502*	7755	*7514*	7768	*7526*	7780	*7538*
23	7644	*7389*	7656	*7401*	7668	*7413*	7681	*7425*	7693	*7437*	7705	*7449*	7717	*7461*	7729	*7474*	7741	*7486*	7753	*7498*
24	7618	*7348*	7631	*7360*	7643	*7372*	7655	*7384*	7667	*7396*	7679	*7408*	7691	*7420*	7703	*7432*	7715	*7445*	7727	*7457*
25	0.7593	*0.7307*	0.7605	*0.7319*	0.7617	*0.7331*	0.7629	*0.7343*	0.7641	*0.7355*	0.7653	*0.7367*	0.7665	*0.7379*	0.7677	*0.7391*	0.7689	*0.7403*	0.7701	*0.7415*
26	7567	*7265*	7579	*7277*	7591	*7289*	7603	*7301*	7615	*7313*	7627	*7325*	7639	*7337*	7651	*7349*	7663	*7361*	7675	*7373*
27	7542	*7222*	7554	*7234*	7566	*7246*	7578	*7258*	7590	*7270*	7602	*7282*	7614	*7294*	7626	*7306*	7638	*7318*	7650	*7330*
28	7517	*7179*	7529	*7191*	7541	*7203*	7553	*7215*	7565	*7226*	7577	*7238*	7589	*7250*	7601	*7262*	7612	*7274*	7624	*7285*
29	7492	*7135*	7504	*7147*	7516	*7159*	7528	*7170*	7540	*7182*	7552	*7194*	7563	*7206*	7575	*7218*	7587	*7230*	7599	*7242*
30	0.7467	*0.7090*	0.7479	*0.7102*	0.7491	*0.7114*	0.7503	*0.7126*	0.7515	*0.7138*	0.7527	*0.7149*	0.7538	*0.7161*	0.7550	*0.7173*	0.7562	*0.7185*	0.7574	*0.7197*
31	7443	*7045*	7455	*7056*	7466	*7068*	7478	*7080*	7490	*7092*	7502	*7104*	7514	*7116*	7525	*7127*	7537	*7139*	7549	*7151*
32	7418	*6998*	7430	*7010*	7442	*7022*	7454	*7034*	7465	*7045*	7477	*7057*	7489	*7069*	7501	*7081*	7512	*7093*	7524	*7104*
33	7394	*6951*	7406	*6963*	7417	*6975*	7429	*6986*	7441	*6998*	7453	*7010*	7464	*7022*	7476	*7033*	7488	*7045*	7500	*7057*
34	7370	*6903*	7382	*6915*	7393	*6927*	7405	*6938*	7417	*6950*	7428	*6962*	7440	*6973*	7452	*6985*	7463	*6997*	7475	*7008*
35	0.7346	*0.6854*	0.7358	*0.6866*	0.7369	*0.6877*	0.7381	*0.6889*	0.7393	*0.6901*	0.7404	*0.6912*	0.7416	*0.6924*	0.7428	*0.6936*	0.7439	*0.6947*	0.7451	*0.6959*
36	7322	*6804*	7334	*6816*	7345	*6827*	7357	*6839*	7369	*6851*	7380	*6862*	7392	*6874*	7403	*6886*	7415	*6897*	7427	*6909*
37	7298	*6753*	7310	*6765*	7322	*6776*	7333	*6788*	7345	*6799*	7356	*6811*	7368	*6823*	7380	*6834*	7391	*6846*	7403	*6857*
38	7275	*6701*	7286	*6713*	7298	*6724*	7310	*6736*	7321	*6747*	7333	*6759*	7344	*6770*	7356	*6782*	7367	*6793*	7379	*6805*
39	7252	*6648*	7263	*6659*	7275	*6671*	7286	*6682*	7298	*6694*	7309	*6705*	7321	*6717*	7332	*6729*	7344	*6740*	7355	*6752*
40	0.7228	*0.6594*	0.7240	*0.6605*	0.7251	*0.6617*	0.7263	*0.6628*	0.7274	*0.6639*	0.7286	*0.6651*	0.7297	*0.6662*	0.7309	*0.6674*	0.7320	*0.6685*	0.7332	*0.6697*
41	7205	*6538*	7217	*6549*	7228	*6561*	7240	*6572*	7251	*6584*	7262	*6595*	7274	*6607*	7285	*6618*	7297	*6630*	7308	*6641*
42	7182	*6481*	7194	*6493*	7205	*6504*	7217	*6515*	7228	*6527*	7239	*6538*	7251	*6550*	7262	*6561*	7274	*6572*	7285	*6584*

	640		641		642		643		644		645		646		647		648		649	
0	0.8421	*0.8361*	0.8434	*0.8374*	0.8447	*0.8387*	0.8461	*0.8400*	0.8474	*0.8413*	0.8487	*0.8427*	0.8500	*0.8440*	0.8513	*0.8453*	0.8526	*0.8466*	0.8539	[illegible]
1	8390	*8326*	8403	*8339*	8416	*8352*	8430	*8365*	8443	*8378*	8456	*8391*	8469	*8404*	8482	*8417*	8495	*8431*	8508	[illegible]
2	8360	*8291*	8373	*8304*	8386	*8317*	8399	*8330*	8412	*8343*	8425	*8356*	8438	*8369*	8451	*8382*	8464	*8395*	8477	[illegible]
3	8329	*8255*	8342	*8268*	8355	*8281*	8368	*8294*	8381	*8307*	8394	*8320*	8407	*8333*	8420	*8346*	8433	*8359*	8446	[illegible]
4	8299	*8220*	8312	*8233*	8325	*8246*	8338	*8259*	8351	*8272*	8364	*8285*	8377	*8298*	8390	*8311*	8403	*8324*	8416	[illegible]
5	0.8269	*0.8185*	0.8282	*0.8198*	0.8295	*0.8211*	0.8308	*0.8224*	0.8321	*0.8236*	0.8334	*0.8249*	0.8347	*0.8262*	0.8360	*0.8275*	0.8373	*0.8288*	0.8386	[illegible]
6	8240	*8149*	8252	*8162*	8265	*8175*	8278	*8188*	8291	*8201*	8304	*8214*	8317	*8227*	8330	*8239*	8343	*8252*	8355	[illegible]
7	8210	*8114*	8223	*8127*	8236	*8139*	8249	*8152*	8261	*8165*	8274	*8178*	8287	*8191*	8300	*8204*	8313	*8216*	8326	[illegible]
8	8181	*8078*	8194	*8091*	8206	*8104*	8219	*8116*	8232	*8129*	8245	*8142*	8258	*8155*	8270	*8168*	8283	*8180*	8296	[illegible]
9	8152	*8042*	8165	*8055*	8177	*8068*	8190	*8080*	8203	*8093*	8215	*8106*	8228	*8119*	8241	*8131*	8254	*8144*	8266	[illegible]
10	0.8123	*0.8006*	0.8136	*0.8019*	0.8148	*0.8031*	0.8161	*0.8044*	0.8174	*0.8057*	0.8186	*0.8070*	0.8199	*0.8082*	0.8212	*0.8095*	0.8224	*0.8108*	0.8237	[illegible]
11	8094	*7970*	8107	*7982*	8120	*7995*	8132	*8008*	8145	*8020*	8158	*8033*	8170	*8046*	8183	*8058*	8195	*8071*	8208	[illegible]
12	8066	*7933*	8078	*7946*	8091	*7958*	8104	*7971*	8116	*7984*	8129	*7996*	8141	*8009*	8154	*8021*	8167	*8034*	8179	[illegible]
13	8038	*7897*	8050	*7909*	8063	*7922*	8075	*7934*	8088	*7947*	8100	*7959*	8113	*7972*	8125	*7984*	8138	*7997*	8151	[illegible]
14	8010	*7860*	8022	*7872*	8035	*7885*	8047	*7897*	8060	*7910*	8072	*7922*	8085	*7935*	8097	*7947*	8110	*7960*	8122	[illegible]
15	0.7982	*0.7822*	0.7994	*0.7835*	0.8007	*0.7847*	0.8019	*0.7860*	0.8032	*0.7872*	0.8044	*0.7885*	0.8056	*0.7897*	0.8069	*0.7909*	0.8081	*0.7922*	0.8094	[illegible]
16	7954	*7785*	7966	*7797*	7979	*7809*	7991	*7822*	8004	*7834*	8016	*7847*	8029	*7859*	8041	*7872*	8053	*7884*	8066	[illegible]
17	7927	*7747*	7939	*7759*	7951	*7771*	7964	*7784*	7976	*7796*	7988	*7808*	8001	*7821*	8013	*7833*	8026	*7846*	8038	[illegible]
18	7899	*7708*	7912	*7721*	7924	*7733*	7936	*7745*	7949	*7758*	7961	*7770*	7973	*7782*	7986	*7795*	7998	*7807*	8010	[illegible]
19	7872	*7669*	7884	*7682*	7897	*7694*	7909	*7706*	7921	*7719*	7934	*7731*	7946	*7743*	7958	*7756*	7971	*7768*	7983	[illegible]
20	0.7845	*0.7630*	0.7857	*0.7643*	0.7870	*0.7655*	0.7882	*0.7667*	0.7894	*0.7679*	0.7907	*0.7692*	0.7919	*0.7704*	0.7931	*0.7716*	0.7943	*0.7728*	0.7956	[illegible]
21	7818	*7591*	7831	*7603*	7843	*7615*	7855	*7627*	7867	*7640*	7880	*7652*	7892	*7664*	7904	*7676*	7916	*7688*	7929	[illegible]
22	7792	*7551*	7804	*7563*	7816	*7575*	7828	*7587*	7841	*7599*	7853	*7611*	7865	*7624*	7877	*7636*	7889	*7648*	7902	[illegible]
23	7766	*7510*	7778	*7522*	7790	*7534*	7802	*7546*	7814	*7558*	7826	*7571*	7838	*7583*	7850	*7595*	7863	*7607*	7875	[illegible]
24	7739	*7469*	7751	*7481*	7764	*7493*	7776	*7505*	7788	*7517*	7800	*7529*	7812	*7541*	7824	*7553*	7836	*7566*	7848	[illegible]
25	0.7713	*0.7427*	0.7725	*0.7439*	0.7737	*0.7451*	0.7750	*0.7463*	0.7762	*0.7475*	0.7774	*0.7487*	0.7786	*0.7499*	0.7798	*0.7511*	0.7810	*0.7523*	0.7822	[illegible]
26	7688	*7385*	7700	*7397*	7712	*7409*	7724	*7421*	7736	*7433*	7748	*7445*	7760	*7457*	7772	*7469*	7784	*7481*	7796	[illegible]
27	7662	*7342*	7674	*7354*	7686	*7366*	7698	*7378*	7710	*7390*	7722	*7402*	7734	*7414*	7746	*7426*	7758	*7438*	7770	[illegible]
28	7636	*7298*	7648	*7310*	7660	*7322*	7672	*7334*	7684	*7346*	7696	*7358*	7708	*7370*	7720	*7382*	7732	*7394*	7744	[illegible]
29	7611	*7254*	7623	*7266*	7635	*7278*	7647	*7289*	7659	*7301*	7670	*7313*	7682	*7325*	7694	*7337*	7706	*7349*	7718	[illegible]
30	0.7586	*0.7209*	0.7598	*0.7220*	0.7610	*0.7232*	0.7621	*0.7244*	0.7633	*0.7256*	0.7645	*0.7268*	0.7657	*0.7280*	0.7669	*0.7292*	0.7681	*0.7303*	0.7693	[illegible]
31	7561	*7163*	7573	*7175*	7584	*7186*	7596	*7198*	7608	*7210*	7620	*7222*	7632	*7234*	7644	*7245*	7655	*7257*	7667	[illegible]
32	7536	*7116*	7548	*7128*	7560	*7140*	7571	*7151*	7583	*7163*	7595	*7175*	7607	*7187*	7618	*7199*	7630	*7210*	7642	[illegible]
33	7511	*7069*	7523	*7080*	7535	*7092*	7547	*7104*	7558	*7115*	7570	*7127*	7582	*7139*	7594	*7151*	7605	*7162*	7617	[illegible]
34	7487	*7020*	7499	*7032*	7510	*7044*	7522	*7055*	7534	*7067*	7545	*7079*	7557	*7090*	7569	*7102*	7580	*7114*	7592	[illegible]
35	0.7462	*0.6971*	0.7474	*0.6982*	0.7486	*0.6994*	0.7497	*0.7006*	0.7509	*0.7017*	0.7521	*0.7029*	0.7532	*0.7041*	0.7544	*0.7052*	0.7556	*0.7064*	0.7567	[illegible]
36	7438	*6920*	7450	*6932*	7462	*6944*	7473	*6955*	7485	*6967*	7496	*6978*	7508	*6990*	7520	*7002*	7531	*7013*	7543	[illegible]
37	7414	*6869*	7426	*6881*	7437	*6892*	7449	*6904*	7461	*6915*	7472	*6927*	7484	*6939*	7495	*6950*	7507	*6962*	7519	[illegible]
38	7390	*6817*	7402	*6828*	7413	*6840*	7425	*6851*	7437	*6863*	7448	*6874*	7460	*6886*	7471	*6897*	7483	*6909*	7494	[illegible]
39	7367	*6763*	7378	*6775*	7390	*6786*	7401	*6798*	7413	*6809*	7424	*6821*	7436	*6832*	7447	*6844*	7459	*6855*	7470	[illegible]
40	0.7343	*0.6708*	0.7355	*0.6720*	0.7366	*0.6731*	0.7378	*0.6743*	0.7389	*0.6754*	0.7400	*0.6766*	0.7412	*0.6777*	0.7423	*0.6789*	0.7435	*0.6800*	0.7446	[illegible]
41	7320	*6652*	7331	*6664*	7343	*6675*	7354	*6687*	7365	*6698*	7377	*6710*	7388	*6721*	7400	*6732*	7411	*6744*	7423	[illegible]
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7353	*6652*	7365	*6664*	7376	*6675*	7388	*6686*	7399	[illegible]

mm Hg	670		671		672		673		674		675		676		677		678		679	
°C	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*
0	0.8816	*0.8756*	0.8829	*0.8769*	0.8842	*0.8782*	0.8855	*0.8795*	0.8868	*0.8808*	0.8882	*0.8821*	0.8895	*0.8834*	0.8908	*0.8848*	0.8921	*0.8861*	0.8934	*0.8874*
1	8784	*8719*	8797	*8732*	8810	*8745*	8823	*8758*	8836	*8771*	8849	*8785*	8862	*8798*	8875	*8811*	8888	*8824*	8902	*8837*
2	8752	*8682*	8765	*8695*	8778	*8709*	8791	*8722*	8804	*8735*	8817	*8748*	8830	*8761*	8843	*8774*	8856	*8787*	8869	*8800*
3	8720	*8646*	8733	*8659*	8746	*8672*	8759	*8685*	8772	*8698*	8785	*8711*	8798	*8724*	8811	*8737*	8824	*8750*	8837	*8763*
4	8688	*8609*	8701	*8622*	8714	*8635*	8727	*8648*	8740	*8661*	8753	*8674*	8766	*8687*	8779	*8700*	8792	*8713*	8805	*8725*
5	0.8657	*0.8572*	0.8670	*0.8585*	0.8683	*0.8598*	0.8696	*0.8611*	0.8709	*0.8624*	0.8722	*0.8637*	0.8734	*0.8650*	0.8747	*0.8663*	0.8760	*0.8676*	0.8773	*0.8689*
6	8626	*8536*	8639	*8548*	8652	*8561*	8664	*8574*	8677	*8587*	8690	*8600*	8703	*8613*	8716	*8626*	8729	*8639*	8742	*8651*
7	8595	*8499*	8608	*8511*	8621	*8524*	8633	*8537*	8646	*8550*	8659	*8563*	8672	*8576*	8685	*8588*	8698	*8601*	8710	*8614*
8	8564	*8462*	8577	*8474*	8590	*8487*	8603	*8500*	8615	*8513*	8628	*8525*	8641	*8538*	8654	*8551*	8667	*8564*	8679	*8577*
9	8534	*8424*	8547	*8437*	8559	*8450*	8572	*8462*	8585	*8475*	8598	*8488*	8610	*8501*	8623	*8513*	8636	*8526*	8649	*8539*
10	0.8504	*0.8387*	0.8516	*0.8400*	0.8529	*0.8412*	0.8542	*0.8425*	0.8554	*0.8438*	0.8567	*0.8450*	0.8580	*0.8463*	0.8593	*0.8476*	0.8605	*0.8488*	0.8618	*0.8501*
11	8474	*8349*	8486	*8362*	8499	*8375*	8512	*8387*	8524	*8400*	8537	*8412*	8550	*8425*	8562	*8438*	8575	*8450*	8588	*8463*
12	8444	*8311*	8457	*8324*	8469	*8337*	8482	*8349*	8494	*8362*	8507	*8374*	8520	*8387*	8532	*8400*	8545	*8412*	8557	*8425*
13	8414	*8273*	8427	*8286*	8439	*8298*	8452	*8311*	8465	*8324*	8477	*8336*	8490	*8349*	8502	*8361*	8515	*8374*	8527	*8385*
14	8385	*8235*	8397	*8247*	8410	*8260*	8423	*8272*	8435	*8285*	8448	*8298*	8460	*8310*	8473	*8323*	8485	*8335*	8498	*8347*
15	0.8356	*0.8196*	0.8368	*0.8209*	0.8381	*0.8221*	0.8393	*0.8234*	0.8406	*0.8246*	0.8418	*0.8259*	0.8431	*0.8271*	0.8443	*0.8284*	0.8456	*0.8296*	0.8468	*0.8309*
16	8327	*8157*	8339	*8170*	8352	*8182*	8364	*8195*	8377	*8207*	8389	*8220*	8401	*8232*	8414	*8244*	8426	*8257*	8439	*8269*
17	8298	*8118*	8310	*8131*	8323	*8143*	8335	*8155*	8348	*8168*	8360	*8180*	8372	*8192*	8385	*8205*	8397	*8217*	8410	*8229*
18	8270	*8078*	8282	*8091*	8294	*8103*	8307	*8116*	8319	*8128*	8331	*8140*	8344	*8153*	8356	*8165*	8368	*8177*	8381	*8190*
19	8241	*8038*	8253	*8051*	8266	*8063*	8278	*8075*	8290	*8088*	8303	*8100*	8315	*8112*	8327	*8125*	8340	*8137*	8352	*8149*
20	0.8213	*0.7998*	0.8225	*0.8010*	0.8237	*0.8023*	0.8250	*0.8035*	0.8262	*0.8047*	0.8274	*0.8059*	0.8287	*0.8072*	0.8299	*0.8084*	0.8311	*0.8096*	0.8323	*0.8108*
21	8185	*7957*	8197	*7969*	8209	*7982*	8222	*7994*	8234	*8006*	8246	*8018*	8258	*8030*	8270	*8043*	8283	*8055*	8295	*8067*
22	8157	*7916*	8169	*7928*	8182	*7940*	8194	*7952*	8206	*7964*	8218	*7977*	8230	*7989*	8242	*8001*	8255	*8013*	8267	*8025*
23	8130	*7874*	8142	*7886*	8154	*7898*	8166	*7910*	8178	*7922*	8190	*7935*	8202	*7947*	8215	*7959*	8227	*7971*	8239	*7983*
24	8102	*7832*	8114	*7844*	8126	*7856*	8138	*7868*	8151	*7880*	8163	*7892*	8175	*7904*	8187	*7916*	8199	*7928*	8211	*7940*
25	0.8075	*0.7789*	0.8087	*0.7801*	0.8099	*0.7813*	0.8111	*0.7825*	0.8123	*0.7837*	0.8135	*0.7849*	0.8147	*0.7861*	0.8159	*0.7873*	0.8171	*0.7885*	0.8183	*0.7897*
26	8048	*7745*	8060	*7757*	8072	*7769*	8084	*7781*	8096	*7793*	8108	*7805*	8120	*7817*	8132	*7829*	8144	*7841*	8156	*7853*
27	8021	*7701*	8033	*7713*	8045	*7725*	8057	*7737*	8069	*7749*	8081	*7761*	8093	*7773*	8105	*7785*	8117	*7797*	8129	*7809*
28	7994	*7656*	8006	*7668*	8018	*7680*	8030	*7692*	8042	*7704*	8054	*7716*	8066	*7728*	8078	*7740*	8090	*7751*	8102	*7763*
29	7968	*7611*	7980	*7622*	7992	*7634*	8003	*7646*	8015	*7658*	8027	*7670*	8039	*7682*	8051	*7694*	8063	*7706*	8075	*7718*
30	0.7941	*0.7564*	0.7953	*0.7576*	0.7965	*0.7588*	0.7977	*0.7600*	0.7989	*0.7612*	0.8001	*0.7623*	0.8013	*0.7635*	0.8024	*0.7647*	0.8036	*0.7659*	0.8048	*0.7671*
31	7915	*7517*	7927	*7529*	7939	*7541*	7951	*7553*	7963	*7564*	7974	*7576*	7986	*7588*	7998	*7600*	8010	*7612*	8022	*7624*
32	7889	*7469*	7901	*7481*	7913	*7493*	7925	*7505*	7936	*7516*	7948	*7528*	7960	*7540*	7972	*7552*	7983	*7564*	7995	*7575*
33	7863	*7421*	7875	*7432*	7887	*7444*	7899	*7456*	7910	*7468*	7922	*7479*	7934	*7491*	7946	*7503*	7957	*7515*	7969	*7525*
34	7838	*7371*	7849	*7383*	7861	*7394*	7873	*7406*	7885	*7418*	7896	*7430*	7908	*7441*	7920	*7453*	7931	*7465*	7943	*7476*
35	0.7812	*0.7321*	0.7824	*0.7332*	0.7836	*0.7344*	0.7847	*0.7356*	0.7859	*0.7367*	0.7871	*0.7379*	0.7882	*0.7390*	0.7894	*0.7402*	0.7906	*0.7414*	0.7917	*0.7425*
36	7787	*7269*	7799	*7281*	7810	*7292*	7822	*7304*	7833	*7316*	7845	*7327*	7857	*7339*	7868	*7350*	7880	*7362*	7892	*7374*
37	7762	*7217*	7773	*7228*	7785	*7240*	7797	*7251*	7808	*7263*	7820	*7274*	7831	*7286*	7843	*7298*	7854	*7309*	7866	*7321*
38	7737	*7163*	7748	*7175*	7760	*7186*	7771	*7198*	7783	*7209*	7795	*7221*	7806	*7232*	7818	*7244*	7829	*7255*	7841	*7267*
39	7712	*7108*	7723	*7120*	7735	*7131*	7747	*7143*	7758	*7154*	7770	*7166*	7781	*7177*	7793	*7189*	7804	*7200*	7816	*7212*
40	0.7687	*0.7053*	0.7699	*0.7064*	0.7710	*0.7075*	0.7722	*0.7087*	0.7733	*0.7098*	0.7745	*0.7110*	0.7756	*0.7121*	0.7768	*0.7133*	0.7779	*0.7144*	0.7791	*0.7156*
41	7663	*6996*	7674	*7007*	7686	*7018*	7697	*7030*	7709	*7041*	7720	*7053*	7731	*7064*	7743	*7076*	7754	*7087*	7766	*7099*
42	7638	*6937*	7650	*6949*	7661	*6960*	7673	*6971*	7684	*6983*	7695	*6994*	7707	*7006*	7718	*7017*	7730	*7028*	7741	*7040*

mm Hg	680		681		682		683		684		685		686		687		688		689	
°C	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*	dry	*sat.*
0	0.8947	*0.8887*	0.8961	*0.8900*	0.8974	*0.8913*	0.8987	*0.8927*	0.9000	*0.8940*	0.9013	*0.8953*	0.9026	*0.8966*	0.9039	*0.8979*	[illegible]	[illegible]	[illegible]	[illegible]
1	8915	*8850*	8928	*8863*	8941	*8876*	8954	*8889*	8967	*8903*	8980	*8916*	8993	*8929*	9006	*8942*	[illegible]	[illegible]	[illegible]	[illegible]
2	8882	*8813*	8895	*8826*	8908	*8839*	8921	*8852*	8934	*8865*	8947	*8878*	8961	*8891*	8974	*8904*	8987	*8918*	9000	*8931*
3	8850	*8776*	8863	*8789*	8876	*8802*	8889	*8815*	8902	*8828*	8915	*8841*	8928	*8854*	8941	*8867*	8954	*8880*	8967	*8893*
4	8818	*8739*	8831	*8752*	8844	*8765*	8857	*8778*	8870	*8791*	8883	*8804*	8896	*8817*	8909	*8830*	8922	*8843*	8935	*8855*
5	0.8786	*0.8702*	0.8799	*0.8715*	0.8812	*0.8727*	0.8825	*0.8740*	0.8838	*0.8753*	0.8851	*0.8766*	0.8864	*0.8779*	0.8877	*0.8792*	0.8890	*0.8805*	0.8902	*0.8818*
6	8755	*8664*	8767	*8677*	8780	*8690*	8793	*8703*	8806	*8716*	8819	*8729*	8832	*8742*	8845	*8754*	8858	*8767*	8870	*8780*
7	8723	*8627*	8736	*8640*	8749	*8653*	8762	*8665*	8775	*8678*	8787	*8691*	8800	*8704*	8813	*8717*	8826	*8730*	8839	*8742*
8	8692	*8589*	8705	*8602*	8718	*8615*	8731	*8628*	8743	*8640*	8756	*8653*	8769	*8666*	8782	*8679*	8794	*8692*	8807	*8704*
9	8661	*8552*	8674	*8564*	8687	*8577*	8699	*8590*	8712	*8603*	8725	*8615*	8738	*8628*	8750	*8641*	8763	*8654*	8776	*8666*
10	0.8631	*0.8514*	0.8643	*0.8526*	0.8656	*0.8539*	0.8669	*0.8552*	0.8681	*0.8565*	0.8694	*0.8577*	0.8707	*0.8590*	0.8719	*0.8603*	0.8732	*0.8615*	0.8745	*0.8628*
11	8600	*8476*	8613	*8488*	8625	*8501*	8638	*8514*	8651	*8526*	8663	*8539*	8676	*8552*	8689	*8564*	8701	*8577*	8714	*8590*
12	8570	*8437*	8583	*8450*	8595	*8463*	8608	*8475*	8620	*8488*	8633	*8500*	8646	*8513*	8658	*8526*	8671	*8538*	8683	*8551*
13	8540	*8399*	8552	*8411*	8565	*8424*	8578	*8437*	8590	*8449*	8603	*8462*	8615	*8474*	8628	*8487*	8640	*8499*	8653	*8512*
14	8510	*8360*	8523	*8373*	8535	*8385*	8548	*8398*	8560	*8410*	8573	*8423*	8585	*8435*	8598	*8448*	8610	*8460*	8623	*8473*
15	0.8481	*0.8321*	0.8493	*0.8334*	0.8505	*0.8346*	0.8518	*0.8358*	0.8530	*0.8371*	0.8543	*0.8383*	0.8555	*0.8396*	0.8568	*0.8408*	0.8580	*0.8421*	0.8593	*0.8433*
16	8451	*8282*	8464	*8294*	8476	*8307*	8488	*8319*	8501	*8331*	8513	*8344*	8526	*8356*	8538	*8369*	8551	*8381*	8563	*8394*
17	8422	*8242*	8434	*8254*	8447	*8267*	8459	*8279*	8471	*8292*	8484	*8304*	8496	*8316*	8509	*8329*	8521	*8341*	8533	*8353*
18	8393	*8202*	8405	*8214*	8418	*8227*	8430	*8239*	8442	*8251*	8455	*8264*	8467	*8276*	8479	*8288*	8492	*8301*	8504	*8313*
19	8364	*8161*	8376	*8174*	8389	*8186*	8401	*8198*	8413	*8211*	8426	*8223*	8438	*8235*	8450	*8248*	8463	*8260*	8475	*8272*
20	0.8336	*0.8121*	0.8348	*0.8133*	0.8360	*0.8145*	0.8372	*0.8157*	0.8385	*0.8170*	0.8397	*0.8182*	0.8409	*0.8194*	0.8421	[illegible]	[illegible]	[illegible]	0.8446	*0.8231*
21	8307	*8079*	8319	*8092*	8332	*8104*	8344	*8116*	8356	*8128*	8368	*8140*	8380	*8153*	8393	[illegible]	[illegible]	[illegible]	[illegible]	*8189*
22	8279	*8038*	8291	*8050*	8303	*8062*	8315	*8074*	8328	*8086*	8340	*8098*	8352	*8111*	8364	*8123*	8376	*8135*	8387	*8147*
23	8251	*7995*	8263	*8007*	8275	*8020*	8287	*8032*	8299	*8044*	8312	*8056*	8324	*8068*	8336	*8080*	8348	*8092*	8360	*8104*
24	8223	*7952*	8235	*7965*	8247	*7977*	8259	*7989*	8271	*8001*	8284	*8013*	8296	*8025*	8308	*8037*	8320	*8049*	8332	*8061*
25	0.8195	*0.7909*	0.8207	*0.7921*	0.8220	*0.7933*	0.8232	*0.7945*	0.8244	*0.7957*	0.8256	*0.7969*	0.8268	*0.7981*	0.8280	*0.7993*	0.8292	*0.8006*	0.8304	*0.8018*
26	8168	*7865*	8180	*7877*	8192	*7889*	8204	*7901*	8216	*7913*	8228	*7925*	8240	*7937*	8252	*7949*	8264	*7961*	8276	*7973*
27	8141	*7821*	8153	*7833*	8165	*7845*	8177	*7857*	8189	*7868*	8201	*7880*	8213	*7892*	8225	*7904*	8236	*7916*	8248	*7928*
28	8114	*7775*	8126	*7787*	8137	*7799*	8149	*7811*	8161	*7823*	8173	*7835*	8185	*7847*	8197	*7859*	8209	*7871*	8221	*7883*
29	8087	*7729*	8099	*7741*	8110	*7753*	8122	*7765*	8134	*7777*	8146	*7789*	8158	*7801*	8170	*7813*	8182	*7825*	8194	*7837*
30	0.8060	*0.7683*	0.8072	*0.7695*	0.8084	*0.7706*	0.8096	*0.7718*	0.8107	*0.7730*	0.8119	*0.7742*	0.8131	*0.7754*	0.8143	*0.7766*	0.8155	*0.7778*	0.8167	*0.7790*
31	8033	*7635*	8045	*7647*	8057	*7659*	8069	*7671*	8081	*7683*	8092	*7694*	8104	*7706*	8116	*7718*	8128	*7730*	8140	*7742*
32	8007	*7587*	8019	*7599*	8031	*7611*	8042	*7622*	8054	*7634*	8066	*7646*	8078	*7658*	8089	*7670*	8101	*7681*	8113	*7693*
33	7981	*7538*	7993	*7550*	8004	*7561*	8016	*7573*	8028	*7585*	8039	*7597*	8051	*7608*	8063	*7620*	8075	*7632*	8086	*7644*
34	7955	*7488*	7966	*7500*	7978	*7511*	7990	*7523*	8002	*7535*	8013	*7547*	8025	*7558*	8037	*7570*	8048	*7582*	8060	*7594*
35	0.7929	*0.7437*	0.7941	*0.7449*	0.7952	*0.7460*	0.7964	*0.7472*	0.7976	*0.7484*	0.7987	*0.7495*	0.7999	*0.7507*	0.8011	*0.7519*	0.8022	*0.7530*	0.8034	*0.7542*
36	7903	*7385*	7915	*7397*	7926	*7409*	7938	*7420*	7950	*7432*	7961	*7443*	7973	*7455*	7985	*7467*	7996	*7478*	8008	*7490*
37	7878	*7332*	7889	*7344*	7901	*7356*	7912	*7367*	7924	*7379*	7936	*7390*	7947	*7402*	7959	*7413*	7970	*7425*	7982	*7437*
38	7852	*7278*	7864	*7290*	7875	*7302*	7887	*7313*	7898	*7325*	7910	*7336*	7922	*7348*	7933	*7359*	7945	*7371*	7956	*7382*
39	7827	*7223*	7839	*7235*	7850	*7246*	7862	*7258*	7873	*7269*	7885	*7281*	7896	*7293*	7908	*7304*	7919	*7316*	7931	*7327*
40	0.7802	*0.7167*	0.7814	*0.7179*	0.7825	*0.7190*	0.7836	*0.7202*	0.7848	*0.7213*	0.7859	*0.7225*	0.7871	*0.7236*	0.7882	*0.7248*	0.7894	*0.7259*	0.7905	*0.7271*
41	7777	*7110*	7789	*7121*	7800	*7133*	7811	*7144*	7823	*7156*	7834	*7167*	7846	*7179*	7857	*7190*	7869	*7201*	7880	*7213*
42	7752	*7051*	7764	*7063*	7775	*7074*	7787	*7085*	7798	*7097*	7809	*7108*	7821	*7120*	7832	*7131*	7844	*7142*	7855	*7154*

mm Hg	710		711		712		713		714		715		716		717		718		719	
°C	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.
0	0.9342	0.9282	0.9355	0.9295	0.9368	0.9308	0.9382	0.9321	0.9395	0.9334	0.9408	0.9348	0.9421	0.9361	0.9434	0.9374	0.9447	0.9387	0.9461	0.9400
1	9308	9243	9321	9256	9334	9270	9347	9283	9360	9296	9373	9309	9387	9322	9400	9335	9413	9348	9426	9361
2	9274	9205	9287	9218	9300	9231	9313	9244	9326	9257	9339	9270	9352	9283	9365	9296	9379	9309	9392	9322
3	9240	9166	9253	9179	9266	9192	9279	9205	9292	9218	9305	9231	9318	9244	9331	9257	9344	9270	9358	9284
4	9207	9128	9220	9141	9233	9154	9246	9167	9259	9180	9272	9193	9285	9206	9298	9219	9311	9232	9324	9245
5	0.9174	0.9089	0.9187	0.9102	0.9200	0.9115	0.9213	0.9128	0.9225	0.9141	0.9238	0.9154	0.9251	0.9167	0.9264	0.9180	0.9277	0.9193	0.9290	0.9205
6	9141	9051	9154	9063	9167	9076	9179	9089	9192	9102	9205	9115	9218	9128	9231	9141	9244	9154	9257	9166
7	9108	9012	9121	9025	9134	9037	9147	9050	9159	9063	9172	9076	9185	9089	9198	9102	9211	9114	9224	9127
8	9076	8973	9088	8986	9101	8998	9114	9011	9127	9024	9140	9037	9152	9050	9165	9062	9178	9075	9191	9088
9	9043	8934	9056	8946	9069	8959	9082	8972	9094	8985	9107	8997	9120	9010	9133	9023	9145	9036	9158	9048
10	0.9011	0.8895	0.9024	0.8907	0.9037	0.8920	0.9049	0.8933	0.9062	0.8945	0.9075	0.8958	0.9088	0.8971	0.9100	0.8983	0.9113	0.8996	0.9126	0.9009
11	8980	8855	8992	8868	9005	8880	9018	8893	9030	8906	9043	8918	9055	8931	9068	8944	9081	8956	9093	8969
12	8948	8815	8961	8828	8973	8841	8986	8853	8998	8866	9011	8878	9024	8891	9036	8904	9049	8916	9061	8929
13	8917	8776	8929	8788	8942	8801	8954	8813	8967	8826	8979	8838	8992	8851	9005	8864	9017	8876	9030	8889
14	8886	8736	8898	8748	8911	8761	8923	8773	8936	8786	8948	8798	8961	8811	8973	8823	8986	8836	8998	8848
15	0.8855	0.8695	0.8867	0.8708	0.8880	0.8720	0.8892	0.8733	0.8905	0.8745	0.8917	0.8758	0.8929	0.8770	0.8942	0.8782	0.8954	0.8795	0.8967	0.8807
16	8824	8655	8836	8667	8849	8679	8861	8692	8874	8704	8886	8717	8899	8729	8911	8742	8923	8754	8936	8766
17	8793	8614	8806	8626	8818	8638	8831	8651	8843	8663	8855	8675	8868	8688	8880	8700	8893	8713	8905	8725
18	8763	8572	8776	8585	8788	8597	8800	8609	8813	8622	8825	8634	8837	8646	8850	8659	8862	8671	8874	8683
19	8733	8530	8745	8543	8758	8555	8770	8567	8782	8580	8795	8592	8807	8604	8819	8617	8832	8629	8844	8641
20	0.8703	0.8488	0.8716	0.8501	0.8728	0.8513	0.8740	0.8525	0.8752	0.8537	0.8765	0.8550	0.8777	0.8562	0.8789	0.8574	0.8801	0.8586	0.8814	0.8599
21	8674	8446	8686	8458	8698	8470	8710	8482	8722	8495	8735	8507	8747	8519	8759	8531	8771	8544	8784	8556
22	8644	8403	8656	8415	8669	8427	8681	8439	8693	8451	8705	8464	8717	8476	8729	8488	8742	8500	8754	8512
23	8615	8359	8627	8371	8639	8384	8651	8396	8663	8408	8676	8420	8688	8432	8700	8444	8712	8456	8724	8468
24	8586	8315	8598	8327	8610	8339	8622	8352	8634	8364	8646	8376	8658	8388	8671	8400	8683	8412	8695	8424
25	0.8557	0.8271	0.8569	0.8283	0.8581	0.8295	0.8593	0.8307	0.8605	0.8319	0.8617	0.8331	0.8629	0.8343	0.8641	0.8355	0.8653	0.8367	0.8665	0.8379
26	8528	8226	8540	8238	8552	8250	8564	8262	8576	8274	8588	8286	8600	8298	8612	8310	8624	8322	8636	8334
27	8500	8180	8512	8192	8524	8204	8536	8216	8548	8228	8560	8240	8572	8252	8584	8264	8596	8276	8608	8287
28	8472	8133	8483	8145	8495	8157	8507	8169	8519	8181	8531	8193	8543	8205	8555	8217	8567	8229	8579	8241
29	8443	8086	8455	8098	8467	8110	8479	8122	8491	8134	8503	8146	8515	8158	8527	8169	8539	8181	8550	8193
30	0.8416	0.8038	0.8427	0.8050	0.8439	0.8062	0.8451	0.8074	0.8463	0.8086	0.8475	0.8098	0.8487	0.8109	0.8499	0.8121	0.8510	0.8133	0.8522	0.8145
31	8388	7990	8400	8002	8411	8013	8423	8025	8435	8037	8447	8049	8459	8061	8471	8072	8482	8084	8494	8095
32	8360	7940	8372	7952	8384	7964	8396	7976	8407	7987	8419	7999	8431	8011	8443	8023	8454	8035	8466	8045
33	8333	7890	8345	7902	8356	7914	8368	7925	8380	7937	8392	7949	8403	7961	8415	7972	8427	7984	8439	7995
34	8306	7839	8317	7851	8329	7862	8341	7874	8353	7886	8364	7897	8376	7909	8388	7921	8399	7933	8411	7944
35	0.8279	0.7787	0.8290	0.7799	0.8302	0.7810	0.8314	0.7822	0.8325	0.7834	0.8337	0.7845	0.8349	0.7857	0.8360	0.7869	0.8372	0.7880	0.8384	0.7892
36	8252	7734	8263	7746	8275	7757	8287	7769	8298	7780	8310	7792	8322	7804	8333	7815	8345	7827	8356	7839
37	8225	7680	8237	7692	8248	7703	8260	7715	8272	7726	8283	7738	8295	7749	8306	7761	8318	7773	8329	7784
38	8199	7625	8210	7636	8222	7648	8233	7660	8245	7671	8256	7683	8268	7694	8280	7706	8291	7717	8303	7729
39	8172	7569	8184	7580	8195	7592	8207	7603	8218	7615	8230	7626	8241	7638	8253	7649	8264	7661	8276	7672
40	0.8146	0.7511	0.8158	0.7523	0.8169	0.7534	0.8181	0.7546	0.8192	0.7557	0.8204	0.7569	0.8215	0.7580	0.8227	0.7592	0.8238	0.7603	0.8249	0.7615
41	8120	7453	8132	7464	8143	7476	8155	7487	8166	7499	8177	7510	8189	7522	8200	7533	8212	7545	8223	7555
42	8094	7393	8106	7405	8117	7416	8129	7427	8140	7439	8151	7450	8163	7462	8174	7473	8186	7484	8197	7495

mm Hg	720		721		722		723		724		725		726		727		728		729	
°C	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.
0	0.9474	0.9413	0.9487	0.9427	0.9500	0.9440	0.9513	0.9453	0.9526	0.9466	0.9539	0.9479	0.9553	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	9439	9374	9452	9388	9465	9401	9478	9414	9491	9427	9505	9440	9518	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	9405	9336	9418	9349	9431	9362	9444	9375	9457	9388	9470	9401	9483	9414	9496	9427	9509	9440	9522	[illegible]
3	9371	9297	9384	9310	9397	9323	9410	9336	9423	9349	9436	9362	9449	9375	9462	9388	9475	9401	9488	9414
4	9337	9258	9350	9270	9363	9283	9376	9296	9388	9309	9401	9322	9414	9335	9427	9348	9440	9361	9453	9374
5	0.9303	0.9218	0.9316	0.9231	0.9329	0.9244	0.9342	0.9257	0.9355	0.9270	0.9368	0.9283	0.9380	0.9296	0.9393	0.9309	0.9406	0.9322	0.9419	0.9335
6	9270	9179	9282	9192	9295	9205	9308	9218	9321	9231	9334	9244	9347	9257	9360	9269	9373	9282	9385	9295
7	9236	9140	9249	9153	9262	9166	9275	9179	9288	9191	9301	9204	9313	9217	9326	9230	9339	9243	9352	9255
8	9203	9101	9216	9113	9229	9126	9242	9139	9255	9152	9267	9165	9280	9177	9293	9190	9306	9203	9319	9216
9	9171	9061	9184	9074	9196	9087	9209	9099	9222	9112	9234	9125	9247	9138	9260	9150	9273	9163	9285	9175
10	0.9138	0.9021	0.9151	0.9034	0.9164	0.9047	0.9176	0.9060	0.9189	0.9072	0.9202	0.9085	0.9214	0.9098	0.9227	0.9110	0.9240	0.9123	0.9253	0.9135
11	9106	8982	9119	8994	9131	9007	9144	9020	9157	9032	9169	9045	9182	9057	9195	9070	9207	9083	9220	9095
12	9074	8942	9087	8954	9099	8967	9112	8979	9124	8992	9137	9005	9150	9017	9162	9030	9175	9042	9187	9055
13	9042	8901	9055	8914	9067	8926	9080	8939	9093	8951	9105	8964	9118	8977	9130	8989	9143	9002	9155	9014
14	9011	8861	9023	8873	9036	8886	9048	8898	9061	8911	9073	8923	9086	8936	9098	8948	9111	8961	9123	8973
15	0.8979	0.8820	0.8992	0.8832	0.9004	0.8845	0.9017	0.8857	0.9029	0.8870	0.9042	0.8882	0.9054	0.8895	0.9067	0.8907	0.9079	0.8920	0.9092	0.8932
16	8948	8779	8961	8791	8973	8804	8986	8816	8998	8829	9010	8841	9023	8853	9035	8866	9048	8878	9060	8891
17	8917	8737	8930	8750	8942	8762	8954	8775	8967	8787	8979	8799	8992	8812	9004	8824	9016	8836	9029	8849
18	8887	8696	8899	8708	8911	8720	8924	8733	8936	8745	8948	8757	8961	8770	8973	8782	8985	8794	8998	8807
19	8856	8653	8868	8666	8881	8678	8893	8690	8905	8703	8918	8715	8930	8727	8942	8740	8955	8752	8967	8764
20	0.8826	0.8611	0.8838	0.8623	0.8850	0.8635	0.8863	0.8648	0.8875	0.8660	0.8887	0.8672	0.8899	0.8684	0.8912	0.8697	0.8924	0.8709	0.8936	0.8721
21	8796	8568	8808	8580	8820	8592	8832	8605	8845	8617	8857	8629	8869	8641	8881	8653	8894	8666	8906	8678
22	8766	8525	8778	8537	8790	8549	8802	8561	8815	8573	8827	8585	8839	8598	8851	8610	8863	8622	8875	8634
23	8736	8481	8748	8493	8761	8505	8773	8517	8785	8529	8797	8541	8809	8553	8821	8566	8833	8578	8845	8590
24	8707	8436	8719	8448	8731	8460	8743	8472	8755	8485	8767	8497	8779	8509	8791	8521	8804	8533	8816	8545
25	0.8678	0.8391	0.8690	0.8403	0.8702	0.8415	0.8714	0.8427	0.8726	0.8439	0.8738	0.8451	0.8750	0.8464	0.8762	0.8476	0.8774	0.8488	0.8786	0.8500
26	8648	8346	8660	8358	8672	8370	8684	8382	8696	8394	8709	8406	8721	8418	8733	8430	8745	8442	8757	8454
27	8620	8299	8632	8311	8644	8323	8655	8335	8667	8347	8679	8359	8691	8371	8703	8383	8715	8395	8727	8407
28	8591	8253	8603	8265	8615	8276	8627	8288	8639	8300	8651	8312	8662	8324	8674	8336	8686	8348	8698	8360
29	8562	8205	8574	8217	8586	8229	8598	8241	8610	8253	8622	8265	8634	8276	8646	8288	8658	8300	8669	8312
30	0.8534	0.8157	0.8546	0.8169	0.8558	0.8181	0.8570	0.8192	0.8581	0.8204	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.8252	0.8641	[illegible]
31	8506	8108	8518	8120	8530	8132	8541	8143	8553	8155	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8612	8214
32	8478	8058	8490	8070	8502	8082	8513	8093	8525	8105	8537	8117	8549	8129	8560	8141	8572	8152	8584	8164
33	8450	8007	8462	8019	8474	8031	8485	8043	8497	8054	8509	8066	8521	8078	8532	8090	8544	8101	8556	8113
34	8423	7956	8434	7968	8446	7979	8458	7991	8469	8003	8481	8014	8493	8026	8505	8038	8516	8050	8528	[illegible]
35	0.8395	0.7904	0.8407	0.7915	0.8419	0.7927	0.8430	0.7939	0.8442	0.7950	0.8454	0.7962	0.8465	0.7974	0.8477	0.7985	0.8489	0.7997	0.8500	[illegible]
36	8368	7850	8380	7862	8391	7873	8403	7885	8415	7897	8426	7908	8438	7920	8449	7932	8461	7943	8473	[illegible]
37	8341	7796	8353	7807	8364	7819	8376	7831	8387	7842	8399	7854	8411	7865	8422	7877	8434	7888	8445	[illegible]
38	8314	7740	8326	7752	8337	7763	8349	7775	8360	7787	8372	7798	8383	7810	8395	7821	8407	7833	8418	[illegible]
39	8287	7684	8299	7695	8311	7707	8322	7718	8334	7730	8345	7741	8357	7753	8368	7764	8380	7776	8391	[illegible]
40	0.8261	0.7626	0.8272	0.7638	0.8284	0.7649	0.8295	0.7661	0.8307	0.7672	0.8318	0.7684	0.8330	0.7695	0.8341	0.7707	0.8353	0.7718	0.8364	[illegible]
41	8235	7567	8246	7579	8257	7590	8269	7602	8280	7613	8292	7625	8303	7636	8315	7647	8326	7659	8338	[illegible]
42	8208	7507	8220	7519	8231	7530	8243	7542	8254	7553	8265	7564	8277	7576	8288	7587	8300	7599	8311	[illegible]

Reduction of Gas Volumes

mm Hg	750		751		752		753		754		755		756		757		758		759	
°C	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.	dry	sat.
0	0.9868	*0.9808*	0.9882	*0.9821*	0.9895	*0.9834*	0.9908	*0.9848*	0.9921	*0.9861*	0.9934	*0.9874*	0.9947	*0.9887*	0.9961	*0.9900*	0.9974	*0.9913*	0.9987	*0.9927*
1	9832	*9768*	9845	*9781*	9859	*9794*	9872	*9807*	9885	*9820*	9898	*9833*	9911	*9846*	9924	*9860*	9937	*9873*	9950	*9885*
2	9797	*9727*	9810	*9740*	9823	*9753*	9836	*9767*	9849	*9780*	9862	*9793*	9875	*9806*	9888	*9819*	9901	*9832*	9914	*9845*
3	9761	*9687*	9774	*9700*	9787	*9713*	9800	*9726*	9813	*9739*	9826	*9752*	9839	*9765*	9852	*9778*	9865	*9791*	9878	*9804*
4	9726	*9647*	9739	*9660*	9752	*9672*	9765	*9685*	9778	*9698*	9790	*9711*	9803	*9724*	9816	*9737*	9829	*9750*	9842	*9763*
5	0.9691	*0.9606*	0.9704	*0.9619*	0.9716	*0.9632*	0.9729	*0.9645*	0.9742	*0.9658*	0.9755	*0.9671*	0.9768	*0.9684*	0.9781	*0.9697*	0.9794	*0.9709*	0.9807	*0.9722*
6	9656	*9566*	9669	*9578*	9682	*9591*	9694	*9604*	9707	*9617*	9720	*9630*	9733	*9643*	9746	*9656*	9759	*9669*	9772	*9681*
7	9621	*9525*	9634	*9538*	9647	*9551*	9660	*9563*	9673	*9576*	9685	*9589*	9698	*9602*	9711	*9615*	9724	*9627*	9737	*9640*
8	9587	*9484*	9600	*9497*	9613	*9510*	9625	*9522*	9638	*9535*	9651	*9548*	9664	*9561*	9676	*9574*	9689	*9586*	9702	*9599*
9	9553	*9443*	9566	*9456*	9578	*9469*	9591	*9481*	9604	*9494*	9617	*9507*	9629	*9520*	9642	*9532*	9655	*9545*	9668	*9558*
10	0.9519	*0.9402*	0.9532	*0.9415*	0.9544	*0.9428*	0.9557	*0.9440*	0.9570	*0.9453*	0.9583	*0.9466*	0.9595	*0.9478*	0.9608	*0.9491*	0.9621	*0.9504*	0.9633	*0.9516*
11	9485	*9361*	9498	*9374*	9511	*9386*	9523	*9399*	9536	*9412*	9549	*9424*	9561	*9437*	9574	*9450*	9587	*9462*	9599	*9475*
12	9452	*9320*	9465	*9332*	9477	*9345*	9490	*9357*	9503	*9370*	9515	*9383*	9528	*9395*	9540	*9408*	9553	*9420*	9566	*9433*
13	9419	*9278*	9432	*9291*	9444	*9303*	9457	*9316*	9469	*9328*	9482	*9341*	9494	*9353*	9507	*9366*	9520	*9378*	9532	*9391*
14	9386	*9236*	9399	*9249*	9411	*9261*	9424	*9274*	9436	*9286*	9449	*9299*	9461	*9311*	9474	*9324*	9486	*9336*	9499	*9349*
15	0.9354	*0.9194*	0.9366	*0.9206*	0.9378	*0.9219*	0.9391	*0.9231*	0.9403	*0.9244*	0.9416	*0.9256*	0.9428	*0.9269*	0.9441	*0.9281*	0.9453	*0.9294*	0.9466	*0.9305*
16	9321	*9152*	9334	*9164*	9346	*9176*	9358	*9189*	9371	*9201*	9383	*9214*	9396	*9226*	9408	*9239*	9421	*9251*	9433	*9263*
17	9289	*9109*	9301	*9121*	9314	*9134*	9326	*9146*	9338	*9158*	9351	*9171*	9363	*9183*	9376	*9196*	9388	*9208*	9400	*9222*
18	9257	*9066*	9269	*9078*	9282	*9091*	9294	*9103*	9306	*9115*	9319	*9128*	9331	*9140*	9343	*9152*	9356	*9165*	9368	*9177*
19	9225	*9022*	9237	*9035*	9250	*9047*	9262	*9059*	9274	*9072*	9287	*9084*	9299	*9096*	9311	*9109*	9324	*9121*	9336	*9133*
20	0.9194	*0.8979*	0.9206	*0.8991*	0.9218	*0.9003*	0.9230	*0.9015*	0.9243	*0.9028*	0.9255	*0.9040*	0.9267	*0.9052*	0.9279	*0.9064*	0.9292	*0.9077*	0.9304	*0.9089*
21	9162	*8934*	9175	*8947*	9187	*8959*	9199	*8971*	9211	*8983*	9223	*8996*	9236	*9008*	9248	*9020*	9260	*9032*	9272	*9044*
22	9131	*8890*	9143	*8902*	9156	*8914*	9168	*8926*	9180	*8938*	9192	*8951*	9204	*8963*	9216	*8975*	9229	*8987*	9241	*8999*
23	9100	*8845*	9112	*8857*	9125	*8869*	9137	*8881*	9149	*8893*	9161	*8905*	9173	*8917*	9185	*8930*	9197	*8942*	9209	*8954*
24	9070	*8799*	9082	*8811*	9094	*8823*	9106	*8835*	9118	*8847*	9130	*8859*	9142	*8872*	9154	*8884*	9166	*8896*	9178	*8908*
25	0.9039	*0.8753*	0.9051	*0.8765*	0.9063	*0.8777*	0.9075	*0.8789*	0.9087	*0.8801*	0.9099	*0.8813*	0.9111	*0.8825*	0.9123	*0.8837*	0.9136	*0.8849*	0.9148	*0.8861*
26	9009	*8706*	9021	*8718*	9033	*8730*	9045	*8742*	9057	*8754*	9069	*8766*	9081	*8778*	9093	*8790*	9105	*8802*	9117	*8814*
27	8979	*8659*	8991	*8671*	9003	*8683*	9015	*8695*	9027	*8706*	9039	*8718*	9051	*8730*	9063	*8742*	9074	*8754*	9086	*8765*
28	8949	*8611*	8961	*8623*	8973	*8634*	8985	*8646*	8997	*8658*	9008	*8670*	9020	*8682*	9032	*8694*	9044	*8706*	9056	*8718*
29	8919	*8562*	8931	*8574*	8943	*8586*	8955	*8598*	8967	*8609*	8979	*8621*	8991	*8633*	9002	*8645*	9014	*8657*	9026	*8669*
30	0.8890	*0.8512*	0.8902	*0.8524*	0.8913	*0.8536*	0.8925	*0.8548*	0.8937	*0.8560*	0.8949	*0.8572*	0.8961	*0.8584*	0.8973	*0.8595*	0.8984	*0.8607*	0.8996	*0.8619*
31	8860	*8462*	8872	*8474*	8884	*8486*	8896	*8498*	8908	*8510*	8919	*8521*	8931	*8533*	8943	*8545*	8955	*8557*	8967	*8569*
32	8831	*8411*	8843	*8423*	8855	*8435*	8867	*8447*	8878	*8458*	8890	*8470*	8902	*8482*	8914	*8494*	8925	*8506*	8937	*8517*
33	8802	*8360*	8814	*8371*	8826	*8383*	8838	*8395*	8849	*8407*	8861	*8418*	8873	*8430*	8885	*8442*	8896	*8453*	8908	*8465*
34	8774	*8307*	8785	*8319*	8797	*8330*	8809	*8342*	8820	*8354*	8832	*8365*	8844	*8377*	8856	*8389*	8867	*8400*	8879	*8412*
35	0.8745	*0.8253*	0.8757	*0.8265*	0.8768	*0.8277*	0.8780	*0.8288*	0.8792	*0.8300*	0.8803	*0.8312*	0.8815	*0.8323*	0.8827	*0.8335*	0.8838	*0.8347*	0.8850	*0.8358*
36	8717	*8199*	8728	*8210*	8740	*8222*	8752	*8234*	8763	*8245*	8775	*8257*	8786	*8269*	8798	*8280*	8810	*8292*	8821	*8303*
37	8689	*8143*	8700	*8155*	8712	*8167*	8723	*8178*	8735	*8190*	8747	*8201*	8758	*8213*	8770	*8224*	8781	*8236*	8793	*8248*
38	8661	*8087*	8672	*8098*	8684	*8110*	8695	*8121*	8707	*8133*	8718	*8145*	8730	*8156*	8741	*8168*	8753	*8179*	8765	*8191*
39	8633	*8029*	8644	*8041*	8656	*8052*	8667	*8064*	8679	*8075*	8690	*8087*	8702	*8098*	8713	*8110*	8725	*8121*	8736	*8133*
40	0.8605	*0.7970*	0.8617	*0.7982*	0.8628	*0.7993*	0.8640	*0.8005*	0.8651	*0.8016*	0.8663	*0.8028*	0.8674	*0.8039*	0.8685	*0.8051*	0.8697	*0.8062*	0.8708	*0.8074*
41	8578	*7910*	8589	*7922*	8601	*7933*	8612	*7945*	8623	*7956*	8635	*7968*	8646	*7979*	8658	*7991*	8669	*8002*	8681	*8013*
42	8550	*7849*	8562	*7861*	8573	*7872*	8585	*7884*	8596	*7895*	8607	*7906*	8619	*7918*	8630	*7929*	8642	*7941*	8653	*7952*

	760		761		762		763		764		765		766		767		768		769	
0	1.0000	*0.9940*	1.0013	*0.9953*	1.0026	*0.9966*	1.0039	*0.9979*	1.0053	*0.9992*	1.0066	*1.0006*	1.0079	*1.0019*	[illegible]	[illegible]	1.0105	*1.0045*	1.0118	*1.0058*
1	0.9963	*9899*	0.9977	*9912*	0.9990	*9925*	0003	*9938*	0016	*9951*	0029	*0.9964*	0042	*0.9978*					0081	*0017*
2	9927	*9858*	9940	*9871*	9953	*9884*	0.9966	*9897*	0.9979	*9910*	0.9992	*9923*	0006	*9936*					0045	*0.9975*
3	9891	*9817*	9904	*9830*	9917	*9843*	9930	*9856*	9943	*9869*	9956	*9882*	0.9969	*9895*					0008	*9934*
4	9855	*9776*	9868	*9789*	9881	*9802*	9894	*9815*	9907	*9828*	9920	*9841*	9933	*9854*	9946	*9867*	9959	*9880*	0.9972	*9893*
5	0.9820	*0.9735*	0.9833	*0.9748*	0.9846	*0.9761*	0.9859	*0.9774*	0.9871	*0.9787*	0.9884	*0.9800*	0.9897	*0.9813*					[illegible]	*0.9852*
6	9785	*9694*	9797	*9707*	9810	*9720*	9823	*9733*	9836	*9746*	9849	*9759*	9862	*9772*					[illegible]	[illegible]
7	9750	*9653*	9762	*9666*	9775	*9679*	9788	*9692*	9801	*9704*	9814	*9717*	9827	*9730*	9839	*9743*	9852	*9756*	9865	*9769*
8	9715	*9612*	9728	*9625*	9740	*9638*	9753	*9650*	9766	*9663*	9779	*9676*	9791	*9689*	9804	*9701*	9817	*9714*	9830	*9727*
9	9680	*9571*	9693	*9583*	9706	*9596*	9718	*9609*	9731	*9622*	9744	*9634*	9757	*9647*	9769	*9660*	9782	*9673*	9795	*9685*
10	0.9646	*0.9529*	0.9659	*0.9542*	0.9671	*0.9554*	0.9684	*0.9567*	0.9697	*0.9580*	0.9709	*0.9593*	0.9722	*0.9605*	0.9735	*0.9618*	0.9748	*0.9631*	0.9760	*0.9643*
11	9612	*9487*	9625	*9500*	9637	*9513*	9650	*9525*	9663	*9538*	9675	*9551*	9688	*9563*	9700	*9576*	9713	*9589*	9726	*9601*
12	9578	*9446*	9591	*9458*	9603	*9471*	9616	*9483*	9629	*9496*	9641	*9509*	9654	*9521*	9666	*9534*	9679	*9546*	9692	*9559*
13	9545	*9404*	9557	*9416*	9570	*9429*	9582	*9441*	9595	*9454*	9607	*9466*	9620	*9479*	9633	*9491*	9645	*9504*	9658	*9517*
14	9511	*9361*	9524	*9374*	9536	*9386*	9549	*9399*	9561	*9411*	9574	*9424*	9586	*9436*	9599	*9449*	9611	*9461*	9624	*9474*
15	0.9478	*0.9319*	0.9491	*0.9331*	0.9503	*0.9344*	0.9516	*0.9356*	0.9528	*0.9369*	0.9541	*0.9381*	0.9553	*0.9394*	0.9566	*0.9406*	0.9578	*0.9419*	0.9590	*0.9431*
16	9445	*9276*	9458	*9288*	9470	*9301*	9483	*9313*	9495	*9326*	9508	*9338*	9520	*9350*	9532	*9363*	9545	*9375*	9557	*9388*
17	9413	*9233*	9425	*9245*	9438	*9258*	9450	*9270*	9462	*9282*	9475	*9295*	9487	*9307*	9499	*9319*	9512	*9332*	9524	*9344*
18	9380	*9189*	9393	*9202*	9405	*9214*	9417	*9226*	9430	*9239*	9442	*9251*	9454	*9263*	9467	*9276*	9479	*9288*	9491	*9300*
19	9348	*9145*	9360	*9158*	9373	*9170*	9385	*9182*	9397	*9195*	9410	*9207*	9422	*9219*	9434	*9232*	9447	*9244*	9459	*9256*
20	0.9316	*0.9101*	0.9328	*0.9114*	0.9341	*0.9126*	0.9353	*0.9138*	0.9365	*0.9150*	0.9377	*0.9163*	0.9390	*0.9175*	0.9402	*0.9187*	0.9414	*0.9199*	0.9427	*0.9212*
21	9284	*9057*	9297	*9069*	9309	*9081*	9321	*9093*	9333	*9105*	9346	*9118*	9358	*9130*	9370	*9142*	9382	*9154*	9394	*9167*
22	9253	*9012*	9265	*9024*	9277	*9036*	9289	*9048*	9302	*9060*	9314	*9072*	9326	*9085*	9338	*9097*	9350	*9109*	9362	*9121*
23	9222	*8966*	9234	*8978*	9246	*8990*	9258	*9002*	9270	*9015*	9282	*9027*	9294	*9039*	9307	*9051*	9319	*9063*	9331	*9075*
24	9191	*8920*	9203	*8932*	9215	*8944*	9227	*8956*	9239	*8968*	9251	*8980*	9263	*8992*	9275	*9005*	9287	*9017*	9299	*9029*
25	0.9160	*0.8873*	0.9172	*0.8885*	0.9184	*0.8897*	0.9196	*0.8909*	0.9208	*0.8922*	0.9220	*0.8934*	0.9232	*0.8946*	0.9244	*0.8958*	0.9256	*0.8970*	0.9268	*0.8982*
26	9129	*8826*	9141	*8838*	9153	*8850*	9165	*8862*	9177	*8874*	9189	*8886*	9201	*8898*	9213	*8910*	9225	*8922*	9237	*8934*
27	9098	*8778*	9110	*8790*	9122	*8802*	9134	*8814*	9146	*8826*	9158	*8838*	9170	*8850*	9182	*8862*	9194	*8874*	9206	*8886*
28	9068	*8730*	9080	*8742*	9092	*8754*	9104	*8766*	9116	*8778*	9128	*8790*	9140	*8801*	9152	*8813*	9164	*8825*	9176	*8837*
29	9038	*8681*	9050	*8693*	9062	*8705*	9074	*8716*	9086	*8728*	9098	*8740*	9109	*8752*	9121	*8764*	9133	*8776*	9145	*8788*
30	0.9008	*0.8631*	0.9020	*0.8643*	0.9032	*0.8655*	0.9044	*0.8667*	0.9056	*0.8678*	0.9067	*0.8690*	0.9079	*0.8702*	0.9091	*0.8714*	0.9103	*0.8726*	0.9115	*0.8738*
31	8979	*8580*	8990	*8592*	9002	*8604*	9014	*8616*	9026	*8628*	9038	*8640*	9049	*8651*	9061	*8663*	9073	*8675*	9085	*8687*
32	8949	*8529*	8961	*8541*	8973	*8553*	8984	*8564*	8996	*8576*	9008	*8588*	9020	*8600*	9031	*8612*	9043	*8623*	9055	*8635*
33	8920	*8477*	8931	*8489*	8943	*8500*	8955	*8512*	8967	*8524*	8978	*8536*	8990	*8547*	9002	*8559*	9014	*8571*	9025	*8583*
34	8891	*8424*	8902	*8436*	8914	*8447*	8926	*8459*	8937	*8471*	8949	*8482*	8961	*8494*	8973	*8506*	8984	*8517*	8996	*8529*
35	0.8862	*0.8370*	0.8873	*0.8382*	0.8885	*0.8393*	0.8897	*0.8405*	0.8908	*0.8417*	0.8920	*0.8428*	0.8932	*0.8440*	0.8943	*0.8452*	0.8955	*0.8463*	0.8967	*0.8475*
36	8833	*8315*	8845	*8327*	8856	*8338*	8868	*8350*	8879	*8362*	8891	*8373*	8903	*8385*	8914	*8396*	8926	*8408*	8938	[illegible]
37	8804	*8259*	8816	*8271*	8828	*8282*	8839	*8294*	8851	*8306*	8862	*8317*	8874	*8329*	8886	*8340*	8897	*8352*	8909	[illegible]
38	8776	*8202*	8788	*8214*	8799	*8225*	8811	*8237*	8822	*8248*	8834	*8260*	8845	*8272*	8857	*8283*	8868	*8295*	8880	[illegible]
39	8748	*8144*	8759	*8156*	8771	*8167*	8782	*8179*	8794	*8190*	8805	*8202*	8817	*8213*	8828	*8225*	8840	*8236*	8852	[illegible]
40	0.8720	*0.8085*	0.8731	*0.8097*	0.8743	*0.8108*	0.8754	*0.8120*	0.8766	*0.8131*	0.8777	*0.8143*	0.8789	*0.8154*	0.8800	*0.8165*	0.8812	*0.8177*	0.8823	[illegible]
41	8692	*8025*	8704	*8036*	8715	*8048*	8726	*8059*	8738	*8071*	8749	*8082*	8761	*8093*	8772	*8105*	8784	*8116*	8795	[illegible]
42	8664	*7963*	8676	*7975*	8687	*7986*	8699	*7998*	8710	*8009*	8721	*8020*	8733	*8032*	8744	*8043*	8756	*8055*	8767	[illegible]

The vital functions of highly developed organisms are closely dependent on the internal aqueous medium and on the maintenance in it of extreme constancy of chemical and physical properties. For the physician a knowledge of some of the properties of aqueous solutions is therefore essential to an understanding of water and electrolyte balance and how it may be modified clinically.

In spite of the advances made in physical chemistry there remain considerable gaps in our knowledge of aqueous solutions. The properties of solutions with concentrations up to 0.01 mol/kg can now be calculated with great accuracy, but for solutions of higher concentration it is necessary to introduce empirical correction factors in order to reconcile measured with theoretical values. In biology and medicine, however, this is of little importance since the approximate formulae derived from theory are sufficiently accurate for most practical purposes.

This section should be read in conjunction with the tables on pages 272–276 and with the chapter 'Water and Electrolyte Balance' (pages 523–530).

Definitions of the concepts atom, molecule and ion

A molecule of a substance is that group of elementary particles existing as kinetic unit in the gaseous phase of the substance at low concentration. The number of molecules per unit volume and their kinetic energy determine the mechanical and thermal properties of ideal gases. Molecules can be made up of one kind of element only or of various elements in combination. The smallest part of an element identifiable in compounds of which the element forms a part is known as an atom.

The 'chemical bonds' binding atoms together to form molecules are usually more than one order of magnitude stronger than the attractive forces between molecules. For this reason the molecules of a substance are often recognizable as units even in the condensed state. This does not apply, however, to many groups of substances, in particular metals and salts; here the term molecule is used in the purely formal sense as the sum of the atoms given in the empirical formula.

Salts are not made up of atoms bound together by orientated forces but of electrically charged atoms – known as ions – situated at the centre of a spherically symmetrical electric field. Atoms are transformed into positive ions (cations) by loss of electrons and into negative ions (anions) by capture of electrons. Since the chemical properties of a particle are determined by the number of electrons it possesses, the properties of ions are completely different from those of the corresponding atoms.

Electrolytes

When an electric current is passed through a salt or its solution in water (or other polar solvent) chemical changes occur at the places where the current enters and leaves (the electrodes). This process is known as electrolysis, a substance undergoing it as an electrolyte. Current passing through an electrolyte is carried by material particles, the ions. Positively charged ions (cations), which migrate in the electric field to the cathode, are indicated by one or more plus signs, depending on their valency, placed after their symbol; in the same way negatively charged ions (anions), which migrate to the anode, are indicated by minus signs (for example, magnesium ion = Mg^{++}, nitrate ion = NO_3^-).

That the ions already exist in the solution and are not formed when the electric field is applied can be demonstrated by measuring properties dependent only on the number of particles present in the solution, such as osmotic pressure, freezing-point depression, etc. (see below). The dissolution of a salt is therefore understood as the statistical distribution of the positive and negative ions forming the solid crystal lattice. This separation of oppositely charged particles is made easier by (1) a higher dielectric constant of the solvent, and (2) a stronger ion–dipole interaction between the ions of the solute and the polar molecules of the solvent (known as solvation or, for water, hydration of the ions). In respect of both (1) and (2) water occupies an almost unique position among solvents.

A solution in which the solute consists of (solvated or hydrated) ions is known as a 'strong' electrolyte (the term electrolyte is also used to describe the solute itself). If ν is the number of ions into which such a solute dissociates, then *n* mole (see page 226) of the solute will form *n*ν mole of particles in solution (positive and negative ions together). Thus for NaCl ν = 2, for $CaCl_2$ ν = 3, while for $K_3Fe(CN)_6$ ν = 4 since $[Fe(CN)_6]^{---}$ is a single complex ion.

Other substances dissociate in solution partly into ions and partly into molecules. These and their solutions are known as 'weak' electrolytes. They include particularly the weak acids and bases (almost all organic acids and bases, carbonic acid, hydrogen sulphide, etc.). The fraction of the total number of molecules dissociated into ions is known as the degree of dissociation α. Dissolution of *n* mole of a weak electrolyte results in the formation of $(\nu\alpha + 1 - \alpha)$ mole of particles. The degree of dissociation α depends to a great extent on the concentration of the solution: the weaker the solution the more complete the dissociation and the closer the degree of dissociation approaches to unity.

Ideal dilute solutions

The thermodynamic treatment of dilute solutions makes use of the concept of the ideal dilute solution. This is a solution in which the molecules of the solute are completely surrounded by solvent molecules, so that any further addition of solvent results in no further interactions between solvent and solute. Under these conditions the properties of the solvent molecules in the solution depend only on the number of dissolved particles and not on their individual properties. Thus the lowering of the vapour pressure of the solvent due to the presence of the solute is proportional to the molar concentration of the solute, and the same applies to the osmotic pressure, freezing-point depression and boiling-point elevation.

The osmotic pressure and freezing-point depression of an ideal dilute aqueous solution are expressed as follows:

$$\text{Osmotic pressure (ideal) in atm} = P_{id} = 0.082055 \times T \times \frac{M}{V_m} \times m_2 \times \nu \qquad (1)$$

$$\text{Freezing-point depression (ideal) in °C} = \Delta T_{id} = 1.86 \times m_2 \times \nu \qquad (2)$$

where 0.082055 = the gas constant R in litre atmosphere; T = absolute temperature in kelvin (K) = 273.15 + °C; 1.86 = the cryoscopic constant (molal freezing-point depression of water); m_2 = molality of the solute (number of moles of undissociated solute per 1000 g water); ν = number of particles into which the solute dissociates at complete dissociation (to be replaced by the factor $\nu\alpha + 1 - \alpha$ when dissociation is not complete); M/V_m = ratio of molar mass to molar volume for water (= 1 at a good approximation). For osmotic pressure and freezing-point depression data for osmotic concentrations of 10–740 mmol/1000 g water see page 272.

From (1) and (2) it follows that

$$P_{(atm)} = 0.0441 \times T \times \Delta T \qquad (3)$$

$$\text{or } P_{(atm,\ at\ 0\,°C)} = 12.05 \times \Delta T \qquad (4)$$

In contrast to (1) and (2), equations (3) and (4) are valid for a wider range of concentrations than those to which the concept of the ideal dilute solution applies, and for this reason the symbols P and ΔT do not bear the index $_{id}$ (ideal).

Real solutions

The higher the solute concentration the wider the solution diverges from the concept of the ideal dilute solution. This divergence can be compensated for by means of a correction factor known as the osmotic coefficient g (= 1 for ideal dilute solutions). At any given concentration a real solution diverges the more widely from the ideal solution the stronger the interactions between the particles in it. For ionic solutions the coefficient g is therefore greater than for solutions of undissociated molecules, and for solutions containing multivalent ions it is particularly large.

For very dilute ionic solutions the coefficient g can be calculated by means of the Debye-Hückel limiting law. Experimentally, it can be obtained from the relationship

$$g = \frac{\Delta T}{\Delta T_{id}} = \frac{\Delta T}{1.86\, m_2 \nu} \qquad (5)$$

where ΔT is the measured freezing-point depression. Most reference books (*International Critical Tables*, *Handbook of Chemistry and Physics*, *Landolt-Börnstein*, etc.) give the latter as a function of the molality m_2, whence g can be obtained by dividing by 1.86 ν in accordance with (5).

In solutions of weak electrolytes the osmotic properties (freezing-point depression, osmotic pressure, etc.) depend mainly on the number of particles, which is a function of the concentration, in other words, they vary with the degree of dissociation α. In this case the divergence from the ideal dilute solution is of importance only in very precise physicochemical measurements, particularly as the ionic concentration remains low.

:asures of concentration

uivalents instead of moles (normality instead of molarity) is al-
;ys necessary when valency or valency change is involved, par-
ularly in acid-base reactions, oxidations and reductions, but it
ould be borne in mind that the normality of a solution can differ
different types of reaction (data on decinormal solutions for titri-
etric analysis are given on page 277)

Freezing-point depression data are always given for concentra-
ons expressed as molality.

e molality of any particular serum component, its concentration,
g, in mg/l serum, must be converted into its concentration in the
rum water.

This conversion can be made by means of either the specific
avity or the protein content of serum. The former method is the
ore accurate and the appropriate factors are given on page 557
*n the basis of protein content the conversion is made by means
f the following formula*[1]

$$\text{Water content of serum in g/l serum} = 984.0 - \left(\frac{0.718 \times \text{protein content}}{\text{in g/l serum}}\right) \quad (6)$$

hat is meant by the expression 'molarity' in any particular case

In order to avoid this confusion the molarity and molality
hould always be related to the *undissociated* solute, otherwise they
hould be clearly specified, for instance 'the molality of all osmoti-
ally active particles'

Osmolarity, osmolality

These terms indicate respectively the molarity and molality an
deal solution of a non-dissociating substance must possess in order
o exert the same osmotic pressure as the solution under consider-
ation. Osmolarity and osmolality are not used in the physicochem-
cal field but find considerable application in the sphere of biology
and medicine[2]. As is clear from the definition, the (real) osmo-
lality is a quantity capable of experimental determination. It can
also be calculated from the molality of the solution provided (1) the
number of molecular fragments (for weak electrolytes the degree of
dissociation α) and (2) the correction factor (osmotic coefficient g)
from the ideal to the real state are known

If weak electrolytes are excluded, the ideal osmolality can be
obtained by multiplying the molality by the number of molecular
fragments. Multiplication of this by the osmotic coefficient g gives
the (real) osmolality as defined above

$$\text{ideal osmolality} = m_s\,\nu \quad (7)$$

$$\text{(real) osmolality} = \text{ideal osmolality} \times g = m_s\,\nu\,g = \Delta T/1.86 \quad (8)$$

For mixed solutions $m_s\nu$ is replaced by the sum $\sum_{i=1}^{n} m_i\nu_i = m_1\nu_1 + m_2\nu_2 + \ldots$ for each of the component solutes. For the sake of simplicity it is assumed that there is no change in the osmotic coefficient when passing from a simple to a mixed solution

In analogy with the mole, the unit of osmolarity and osmolality is the osmole (osm)

Applications

To obtain freezing-point depression and osmotic pressure from osmolality see the table on page 272

Osmolality of blood serum from freezing-point depression (0.56 °C) (table on page 272)

Columns 5 and 6 of the table show that the (real) osmolality of serum is 302.1 mmol.

Sodium chloride and glucose solutions (table on page 273)

(*a*) *The weights* of NaCl and glucose (or fructose) *corresponding to given ideal osmolalities* are obtained from columns 1/2 and 1/6. Column 7 gives the corresponding calorific values for glucose and fructose

(*b*) *The ideal osmolalities corresponding to given weights* of NaCl and glucose (or fructose) are obtained from columns 11/12 and 11/13. The corresponding calorific values for glucose and fructose are given in column 14

... when the solution becomes a mixed solution ... g for NaCl for 500 mmol/1000 g water is 1.0893. Since 100 mmol are to be added by means of NaCl, the required weight (see example ...) is 2.922 × 1.0893 = 3.183 g NaCl

(*d*) *Isotonic solutions* The concentrations required to yield these

References

[1] Welt, L. G., in Duncan, G. G. (Ed.), *Diseases of Metabolism*, 5th ed., Saunders, Philadelphia, 1964, page 449

[2] Netter, H., *Theoretische Biochemie*, Springer, Berlin, 1959, page 108

Aqueous Solutions – Calculation of Freezing-point Depression and Osmotic Pressure

(For explanation see pages 270–271)

Real osmolality (mmol/1000 g water)	Freezing-point depression (ΔT °C)	Osmotic pressure at 0 °C (atm)	Osmotic pressure at 38 °C* (atm)	Freezing-point depression (ΔT °C)	Real osmolality (mmol/1000 g water)	Osmotic pressure at 0 °C (atm)	Osmotic pressure at 38 °C* (atm)
1	2	3	4	5	6	7	8
10	0.019	0.22	0.26	0.01	5.4	0.12	0.14
20	0.037	0.45	0.51	02	10.7	0.24	0.28
30	0.056	0.67	0.77	03	16.1	0.36	0.41
40	0.074	0.90	1.01	04	21.5	0.48	0.55
50	0.093	1.12	1.27	0.05	26.9	0.60	0.69
60	0.112	1.35	1.52	06	32.3	0.72	0.82
70	0.130	1.57	1.78	07	37.6	0.84	0.95
80	0.149	1.79	2.03	08	43.0	0.97	1.09
90	0.167	2.02	2.28	09	48.4	1.09	1.23
100	0.186	2.24	2.54	0.10	53.8	1.21	1.37
10	0.205	2.47	2.79	11	59.2	1.33	1.50
20	0.223	2.69	3.05	12	64.6	1.45	1.64
30	0.242	2.91	3.30	13	70.0	1.57	1.78
40	0.260	3.14	3.55	14	75.3	1.69	1.92
50	0.279	3.36	3.80	0.15	80.7	1.81	2.05
60	0.297	3.59	4.06	16	86.1	1.93	2.18
70	0.316	3.81	4.31	17	91.5	2.05	2.32
80	0.334	4.03	4.57	18	96.9	2.17	2.46
90	0.353	4.26	4.83	19	102.3	2.29	2.59
200	0.371	4.48	5.07	0.20	107.7	2.41	2.73
10	0.390	4.71	5.33	21	113.0	2.53	2.87
20	0.408	4.93	5.58	22	118.4	2.65	3.01
30	0.427	5.16	5.84	23	123.8	2.77	3.14
40	0.445	5.38	6.09	24	129.2	2.89	3.28
50	0.464	5.60	6.34	0.25	134.6	3.02	3.42
60	0.482	5.83	6.59	26	140.0	3.14	3.56
70	0.501	6.05	6.85	27	145.4	3.26	3.68
80	0.519	6.28	7.10	28	150.8	3.38	3.82
90	0.537	6.50	7.36	29	156.2	3.50	3.96
300	0.556	6.72	7.62	0.30	161.6	3.62	4.10
10	0.574	6.95	7.87	31	167.0	3.74	4.23
20	0.593	7.17	8.12	32	172.4	3.86	4.37
30	0.611	7.40	8.37	33	177.8	3.98	4.51
40	0.630	7.62	8.63	34	183.2	4.10	4.65
50	0.648	7.84	8.88	0.35	188.6	4.23	4.78
60	0.667	8.07	9.14	36	194.0	4.35	4.92
70	0.685	8.29	9.39	37	199.4	4.47	5.06
80	0.704	8.52	9.64	38	204.8	4.59	5.20
90	0.722	8.74	9.90	39	210.2	4.71	5.33
400	0.741	8.97	10.15	0.40	215.5	4.84	5.47
10	0.759	9.19	10.40	41	220.9	4.96	5.61
20	0.778	9.41	10.66	42	226.3	5.08	5.75
30	0.796	9.64	10.92	43	231.8	5.20	5.88
40	0.815	9.86	11.16	44	237.2	5.32	6.02
50	0.833	10.09	11.42	0.45	242.6	5.44	6.16
60	0.851	10.31	11.67	46	248.0	5.56	6.30
70	0.870	10.53	11.93	47	253.4	5.68	6.43
80	0.887	10.76	12.17	48	258.8	5.80	6.57
90	0.906	10.98	12.43	49	264.2	5.92	6.71
500	0.925	11.21	12.69	0.50	269.6	6.04	6.85
10	0.943	11.43	12.94	51	275.0	6.16	6.98
20	0.962	11.66	13.20	52	280.4	6.28	7.11
30	0.980	11.88	13.45	53	285.8	6.40	7.25
40	0.998	12.10	13.70	54	291.2	6.52	7.39
50	1.017	12.33	13.95	0.55	296.7	6.64	7.53
60	1.035	12.55	14.21	56	302.1	6.77	7.66
70	1.054	12.78	14.47	57	307.5	6.89	7.80
80	1.072	13.00	14.72	58	312.9	7.02	7.94
90	1.090	13.22	14.97	59	318.3	7.14	8.07
600	1.109	13.45	15.22	0.60	323.7	7.26	8.21
10	1.127	13.67	15.48	61	329.2	7.38	8.35
20	1.146	13.90	15.73	62	334.6	7.49	8.49
30	1.164	14.12	15.99	63	340.0	7.62	8.62
40	1.182	14.34	16.24	64	345.4	7.74	8.76
50	1.201	14.57	16.49	0.65	350.8	7.86	8.90
60	1.219	14.79	16.75	66	356.2	7.98	9.04
70	1.238	15.02	17.00	67	361.6	8.10	9.17
80	1.256	15.24	17.26	68	367.0	8.22	9.31
90	1.274	15.47	17.51	69	372.5	8.34	9.45
700	1.292	15.69	17.77	0.70	377.9	8.47	9.59
10	1.311	15.91	18.01	71	383.3	8.59	9.72
20	1.329	16.14	18.27	72	388.7	8.71	9.86
30	1.347	16.36	18.52	73	394.2	8.84	10.00
40	1.365	16.59	18.78	74	399.6	8.96	10.14

* Normal blood temperature = ca. 38 °C = 311.15 K.

Aqueous Solutions – Calculation of Salt and Glucose Concentrations

(For explanation see page 271)

lues in columns 3–5 and 8–10 have been calculated for the osmolalities in column 1 read as real osmotic concentrations (millimoles or grammes per 1000 g ter) The osmotic coefficients *g* have been obtained by interpolation from the data of Scatchard and Prentiss, *J Amer chem Soc*, 55, 4355 (1933), for NaCl and Roth, W.A, *Z phys Chem*, 43, 539 (1903), for glucose

Osmolality (ideal)	Common salt (NaCl, mol wt 58 443): Corresponds to a weight of	Common salt: Weight necessary when the mmol in column 1 are required to be added to bring the total osmolality to 300 mmol	Common salt: Osmotic coefficient corresponding to the osmolality in column 1 read as real osmolality		D Glucose* ($C_6H_{12}O_6$, mol wt 180 16): Corresponds to a weight of	D Glucose: Corresponds to a calorific value of	D Glucose: Weight necessary when the mmol in column 1 are required to be added to bring the total osmolality to 300 mmol	D Glucose: Osmotic coefficient corresponding to the osmolality in column 1 read as real osmolality			Common salt (NaCl): Corresponds to an ideal osmolality of	D-Glucose* ($C_6H_{12}O_6$): Corresponds to an ideal osmolality of	D-Glucose: Corresponds to a calorific value of
mmol	g	g	*g*	1/*g*	g	cal**	g	*g*	1/*g*	g	mmol	mmol	cal**
1	2	3	4	5	6	7	8	9	10	11	12	13	14
10	0 292	0 315	0 9778	1 0227	1 802	7 53	1 777	1 0005	0 9995	1	34 22	5 55	4 18
20	0 584	0 630	0 9703	1 0306	3 603	15 07	3 554	1 0009	0 9991	2	68 44	11 10	8 36
30	0 877	0 947	0 9653	1 0359	5 405	22 60	5 331	1 0014	0 9986	3	102 66	16 65	12 55
40	1 169	1 262	0 9612	1 0404	7 206	30 14	7 108	1 0018	0 9982	4	136 89	22 20	16 73
50	1 461	1 577	0 9579	1 0440	9 008	37 67	8 885	1 0023	0 9977	5	171 11	27 75	20 91
60	1 753	1 892	0 9550	1 0471	10 810	45 21	10 662	1 0028	0 9972	6	205 33	33 30	25 09
70	2 046	2 208	0 9525	1 0499	12 611	52 74	12 439	1 0032	0 9968	7	239 55	38 85	29 27
80	*2 338*	*2 524*	*0 9503*	*1 0523*	*14 413*	*60 27*	*14 217*	*1 0037*	*0 9963*	*8*	*273 77*	*44 41*	33 46
90	2 630	2 839	0 9482	1 0546	16 214	67 81	15 994	1 0041	0 9959	9	307 99	49 96	37 64
100	2 922	3 154	0 9463	1 0567	18 016	75 34	17 771	1 0046	0 9954	10	342 22	55 51	41 82
10	3 214	3 469	0 9448	1 0584	19 818	82 88	19 548	1 0051	0 9949	11	376 44	61 06	46 00
20	3 507	3 785	0 9432	1 0602	21 619	90 41	21 325	1 0055	0 9945	12	410 66	66 61	50 18
30	3 799	4 101	0 9418	1 0618	23 421	97 95	23 102	1 0060	0 9940	13	444 88	72 16	54 37
40	4 091	4 416	0 9405	1 0633	25 222	105 48	24 879	1 0064	0 9936	14	479 10	77 71	58 55
50	4 383	4 731	0 9392	1 0647	27 024	113 01	26 656	1 0069	0 9931	15	513 32	83 26	62 73
60	4 675	5 047	0 9380	1 0661	28 826	120 55	28 433	1 0074	0 9927	16	547 54	88 81	66 91
70	4 968	5 362	0 9368	1 0675	30 627	128 08	30 210	1 0078	0 9923	17	581 77	94 36	71 09
80	5 260	5 678	0 9357	1 0687	32.429	135 62	31 987	1 0083	0 9918	18	615 99	99 91	75 28
90	5 552	5 993	0 9347	1 0699	34 230	143 15	33 764	1 0087	0 9914	19	650 21	105 46	79 46
200	5 844	6 308	0 9337	1 0710	36 032	150 68	35 541	1 0092	0 9909	20	684 43	111 01	83 64
10	6 137	6 624	0 9328	1 0720	37 834	158 22	37 318	1 0097	0 9904	21	718 65	116 56	87 82
20	6 429	6 939	0 9319	1 0731	39 635	165 75	39 096	1 0101	0 9900	22	752 87	122 11	92 00
30	6 721	7 255	0 9311	1 0740	41 437	173 29	40 873	1 0106	0 9895	23	787 09	127 66	96 19
40	7 013	7 570	0 9304	1 0748	43 238	180 82	42 650	1 0110	0 9891	24	821 32	133 22	100 37
50	7 305	7 885	0 9297	1 0756	45 040	188 36	44 427	1 0115	0 9886	25	855 54	138 77	104 55
60	7 598	8 201	0 9290	1 0764	46 842	195 89	46 204	1 0120	0 9881	26	889 76	144 32	108 73
70	7 890	8 516	0 9283	1 0772	48 643	203 43	47 981	1 0124	0 9878	27	923 98	149 87	112 91
80	8 182	8 832	0 9276	1 0780	50 445	210 96	49 758	1 0129	0 9873	28	958 20	155 42	117 10
90	8 474	9 147	0 9270	1 0787	52 246	218 49	51 535	1 0133	0 9869	29	992 42	160 97	121 28
300	8 766	9 463	0 9264	1 0794	54 048	226 03	53 312	1 0138	0 9864	30	1026 65	166 52	125 46
10	9 059		0 9258	1 0801	55 850	233 56		1 0143	0 9859	31	1060 87	172 06	129 64
20	9 351		0 9252	1 0808	57 651	241 10		1 0147	0 9855	32	1095 09	177 62	133 82
30	9 643		0 9246	1 0815	59 453	248 63		1 0152	0 9850	33	1129 31	183 17	138 01
40	9 935		0 9241	1 0821	61 254	256 17		1 0156	0 9846	34	1163 53	188 72	142 19
50	10 228		0 9236	1 0827	63 056	263 70		1 0161	0 9842	35	1197 75	194 27	146 37
60	10 520		0 9232	1 0832	64 858	271 23		1 0166	0 9837	36	1231 97	199 82	150 55
70	10 812		0 9227	1 0838	66 659	278 77		1 0170	0 9833	37	1266 20	205 37	154 73
80	11 104		0 9223	1 0842	68 461	286 30		1 0175	0 9828	38	1300 42	210 92	158 92
90	11 396		0 9219	1 0847	70 262	293 84		1 0179	0 9824	39	1334 64	216 47	163 10
400	11 689		0 9215	1 0852	72 064	301 37		1 0183	0 9820	40	1368 86	222 03	167 28
10	11 981		0 9211	1 0857	73 866	308 91		1 0187	0 9816	41	1403 08	227 58	171 46
20	12 273		0 9207	1 0861	75 667	316 44		1 0192	0 9812	42	1437 30	233 13	175 64
30	12 565		0 9204	1 0864	77 469	323 98		1 0196	0 9808	43	1471 52	238 68	179 82
40	12 857		0 9200	1 0868	79 270	331 51		1 0201	0 9803	44	1505 75	244 23	184 00
50	13 150		0 9196	1 0874	81 072	339 04		1 0205	0 9799	45	1539 97	249 78	188 19
60	13 442		0 9192	1 0878	82 874	346 58		1 0209	0 9795	46	1574 19	255 33	192 37
70	13 734		0 9189	1 0882	84 675	354 11		1 0214	0 9790	47	1608 41	260 88	196 55
80	14 026		0 9185	1 0887	86 477	361 64		1 0218	0 9787	48	1642 63	266 43	200 74
90	14 319		0 9182	1 0891	88 278	369 18		1 0222	0 9783	49	1676 85	271 98	204 92
500	14 611		0 9180	1 0893	90 080	376 72		1 0226	0 9779	50	1711 08	277 53	209 10
10	14 903		0 9177	1 0897	91 882	384 25		1 0230	0 9775	51	1745 30	283 08	213 28
20	15 195		0 9174	1 0900	93 683	391 78		1 0234	0 9771	52	1779 52	288 63	217,46
30	15 487		0 9172	1 0903	95 485	399 32		1 0238	0 9767	53	1813 74	294 18	221 65
40	15 780		0 9170	1 0905	97 286	406 85		1 0242	0 9764	54	1847 96	299 73	225 82
50	16 072		0 9167	1 0908	99 088	414 39		1 0245	0 9761	55	1882 18	305 28	230 01
60	16 364		0 9165	1 0911	100 890	421 92		1 0249	0 9757	56	1916 40	310 84	234 19
70	16 656		0 9163	1 0913	102 691	429 45		1 0253	0 9753	57	1950 63	316 39	238 37
80	16 949		0 9161	1 0916	104 493	436 98		1 0256	0 9750	58	1984 85	321 94	242 56
90	17 241		0 9159	1 0918	106 294	444 52		1 0260	0 9747	59	2019 07	327 49	246 73
600	17 533		0 9157	1 0921	108 096	452 06		1 0263	0 9744	60	2053 29	333 04	250 92
10	17 825		0 9155	1 0923	109 898	459 59		1 0267	0 9740	61	2087 51	338 59	255 10
20	18 117		0 9153	1 0925	111 699	467 13		1 0270	0 9737	62	2121 73	344 14	259 28
30	18 410		0 9152	1 0927	113 501	474 66		1 0273	0 9734	63	2155 95	349 69	263 47
40	18 702		0 9150	1 0929	115 302	482 19		1 0276	0 9731	64	2190 18	355 24	267 65
50	18 994		0 9148	1 0931	117 104	489 73		1 0279	0 9729	65	2224 40	360 79	271 83
60	19 286		0 9146	1 0934	118 906	497 26		1 0282	0 9726	66	2258 62	366 34	276 01
70	19 578		0 9145	1 0935	120 707	504 80		1 0285	0 9723	67	2292 84	371 89	280 19
80	19 871		0 9144	1 0936	122 509	512 33		1 0288	0 9720	69	2327 06	377 44	284 38
90	20 163		0 9142	1 0938	124 310	519 87		1 0291	0 9717	69	2361 28	382 99	288 56
700	20 455		0 9140	1 0941	126 112	527 40		1 0293	0 9715	70	2395 51	388 55	292 74
10	20 747		0 9139	1 0942	127 914	534 91		1 0296	0 9713	71	2429 73	394 09	296 92
20	21 039		0 9137	1 0945	129 715	542 47		1 0298	0 9711	72	2463 95	399 65	301 10
30	21 332		*0 9135*	*1 0947*	*131 517*	*550 00*		1 0300	0 9709	73	2498 17	405 20	305 29
40	21 624		0 9134	1 0948	133 318	557 54		1 0302	0 9707	74	2532 39	410 75	309 47

Column 3, from 310 mmol onward: These values are obtained by dividing the values in column 2 by 0 926 4 or multiplying them by 1 079 4 (*g* or 1/*g* for NaCl at an osmolality of 300 mmol or mosm)

Column 8, from 310 mmol onward: These values are obtained by dividing the values in column 6 by 1 013 8 or multiplying them by 0 986 4 (*g* or 1/*g* for glucose at an osmolality of 300 mmol or mosm)

* Since the elementary composition of fructose is the same as that of glucose columns 6, 7, 13 and 14 can also be used for fructose Note that the osmotic coefficient *g* for fructose is not the same as that for glucose

** Loewy's value for the calorific equivalent of carbohydrates (4 182 calories per gramme) has been used

No.	Electrolyte (data for 1 g unless otherwise stated)		Molecular weight	Undissociated solute	Solubility† (gramme per 1000 ml water)		Cation			Anion			Milliosmoles††
				mmol	cold	hot	mEq	mg		mEq	mg		
	Calcium (Ca)												
1	acetate	$Ca(C_2H_3O_2)_2 + H_2O$	176.19	5.68	436^{20}	331^{100}	11.35	227	Ca^{++}	11.35	670	$C_2H_3O_2^-$	17.03
2		$Ca(C_2H_3O_2)_2 + 2H_2O$	194.20	5.15	459^{0}	411^{80}	10.30	206	Ca^{++}	10.30	608	$C_2H_3O_2^-$	15.45
3	chloride	$CaCl_2 + 2H_2O$	147.02	6.80	1812^{60}	2106^{100}	13.60	273	Ca^{++}	13.60	482	Cl^-	20.40
4		$CaCl_2 + 6H_2O$	219.08	4.56	1175^{0}	2013^{30}	9.13	183	Ca^{++}	9.13	324	Cl^-	13.69
5	citrate	$Ca_3(C_6H_5O_7)_2 + 4H_2O$	570.51	1.75	8.5^{18}	9.6^{23}	10.52	211	Ca^{++}	10.52	663	$C_6H_5O_7^{---}$	8.76
6	D-gluconate	$Ca(C_6H_{11}O_7)_2 + H_2O$	448.40	2.23	33^{15}		4.46	89	Ca^{++}	4.46	870	$C_6H_{11}O_7^-$	6.69
7	lactate	$Ca(C_3H_5O_3)_2 + 5H_2O$	308.30	3.24	31^{0}	79^{30}	6.49	130	Ca^{++}	6.49	578	$C_3H_5O_3^-$	9.73
8	laevulinate	$Ca(C_5H_7O_3)_2 + 2H_2O$	306.33	3.26	400		6.53	131	Ca^{++}	6.53	752	$C_5H_7O_3^-$	9.79
9	oxide (lime)*	CaO	56.08	17.83	1.31^{10}d	0.7^{80}d	35.66	715	Ca^{++}				
10	phosphate, dibasic	$CaHPO_4 + 2H_2O$	172.09	5.81	0.2^{25}	0.75^{100}	11.62	233	Ca^{++}	11.62	558/180	HPO_4^{--} / P	11.62
11	thiosulphate	$CaS_2O_3 + 6H_2O$	260.30	3.84	1000^{3}	d	7.68	154	Ca^{++}	7.68	431/246	$S_2O_3^{--}$ / S	7.68
	Chlorine (Cl)												
12	Ammonium chloride	NH_4Cl	53.49	18.69	294^{0}	773^{100}	18.69	337	NH_4^+	18.69	663	Cl^-	37.39
13	Hydrochloric acid (10% solution)												
	1 g	(0.1 g HCl)	36.46	2.74	∞	∞	2.74	2.8	H^+	2.74	97.2	Cl^-	5.45
	1 ml	(0.1047 g HCl)	36.46	2.87	∞	∞	2.87	2.9	H^+	2.87	101.8	Cl^-	5.74
	See also Calcium (**3**, **4**), Magnesium (**14**, **15**), Potassium (**22**) and Sodium (**35**)												
	Magnesium (Mg)												
14	chloride	$MgCl_2$	95.21	10.50	542.5^{20}	727^{100}	21.00	255	Mg^{++}	21.0	745	Cl^-	31.50
15		$MgCl_2 + 6H_2O$	203.30	4.92	1127^{0}	1559^{100}	9.84	120	Mg^{++}	9.84	349	Cl^-	14.75
16	hydroxide	$Mg(OH)_2$	58.32	17.14	0.009^{18}	0.04^{100}	34.29	417	Mg^{++}				
17	oxide (magnesia)*	MgO	40.30	24.80	0.0062	0.086^{30}	49.60	603	Mg^{++}				
18	sulphate (Epsom salts)	$MgSO_4 + 7H_2O$	246.47	4.06	483^{10}	641^{40}	8.11	98.6	Mg^{++}	8.11	390/130	SO_4^{--} / S	8.11
	Phosphorus (P)												
	See Calcium (**10**), Potassium (**26**, **27**) and Sodium (**30**, **31**, **40–42**)												
	Potassium (K)												
19	acetate	$K(C_2H_3O_2)$	98.15	10.19	2530^{20}	4920^{62}	10.19	398	K^+	10.19	602	$C_2H_3O_2^-$	20.38
20	bicarbonate	$KHCO_3$	100.12	9.99	183^{0}	375^{60}	9.99	391	K^+	9.99	609	HCO_3^-	19.98
21	bromide	KBr	119.01	8.40	535^{0}	1040^{100}	8.40	329	K^+	8.40	671	Br^-	16.81
22	chloride	KCl	74.56	13.41	276^{0}	567^{100}	13.41	524	K^+	13.41	476	Cl^-	26.83
23	citrate	$K_3(C_6H_5O_7) + H_2O$	324.42	3.08	1670^{15}	1997^{31}	9.25	362	K^+	9.25	583	$C_6H_5O_7^{---}$	12.33
24	D-gluconate	$K(C_6H_{11}O_7)$	234.25	4.27			4.27	167	K^+	4.27	833	$C_6H_{11}O_7^-$	8.54
25	oxide*	K_2O	94.20	10.62	d	d	21.23	830					
26	phosphate, monobasic	KH_2PO_4	136.09	7.35	330^{25}	v.s.	7.35	287	K^+	14.70	705/228	HPO_4^{--} / P	22.04
							7.35	7.4	H^+				
27	phosphate, dibasic	K_2HPO_4	174.18	5.74	1670^{20}	v.s.	11.48	449	K^+	11.48	551/178	HPO_4^{--} / P	17.22
	Sodium (Na)												
28	acetate	$Na(C_2H_3O_2) + 3H_2O$	136.08	7.35	602^{0}	2306^{80}	7.35	169	Na^+	7.35	434	$C_2H_3O_2^-$	14.70
29	acid citrate	$Na_2H(C_6H_5O_7) + 1\frac{1}{2}H_2O$	263.11	3.80	v.s.	v.s.	7.60	175	Na^+	7.60	723	$H(C_6H_5O_7)^{--}$	11.40
							7.60	175	Na^+	11.4	719	$C_6H_5O_7^{---}$	15.21
							3.80	3.83	H^+				
30	acid phosphate	$NaH_2PO_4 + H_2O$	137.99	7.25	599^{0}	1824^{50}	7.25	167	Na^+	14.49	696/224	HPO_4^{--} / P	21.74
							7.25	7.3	H^+				
31		$NaH_2PO_4 + 2H_2O$	156.01	6.41	753^{0}	1797^{40}	6.41	147	Na^+	12.82	615/199	HPO_4^{--} / P	19.23
							6.41	6.5	H^+				
32	aminosalicylate	$Na(C_7H_6O_3N) + 2H_2O$	211.15	4.74			4.74	109	Na^+	4.74	720	$C_7H_6O_3N^-$	9.47
33	bicarbonate**	$NaHCO_3$	84.01	11.90	69^{0}	164^{60}	11.90	274	Na^+	11.90	726	HCO_3^-	23.81
34	bromide	$NaBr$	102.89	9.72	542^{80}	548^{100}	9.72	223	Na^+	9.72	777	Br^-	19.44
35	chloride (common salt)	$NaCl$	58.44	17.11	357^{0}	398^{100}	17.11	393	Na^+	17.11	607	Cl^-	34.22
36	citrate	$Na_3(C_6H_5O_7) + 2H_2O$	294.10	3.40	720^{25}	1670^{100}	10.19	235	Na^+	10.19	643	$C_6H_5O_7^{---}$	13.60
37		$Na_3(C_6H_5O_7) + 5\frac{1}{2}H_2O$	357.16	2.80	926^{25}	2500^{100}	8.40	193	Na^+	8.40	529	$C_6H_5O_7^{---}$	11.20
38	lactate**	$Na(C_3H_5O_3)$	112.06	8.92	v.s.		8.92	205	Na^+	8.92	795	$C_3H_5O_3^-$	17.84
39	oxide*	Na_2O	61.98	16.13	d	d	32.26	742	Na^+				
40	phosphate	Na_2HPO_4	141.96	7.04		1022^{100}	14.09	324	Na^+	14.09	676/218	HPO_4^{--} / P	21.13
41		$Na_2HPO_4 + 2H_2O$	177.99	5.62	1006^{50}	1290^{80}	11.24	258	Na^+	11.24	539/174	HPO_4^{--} / P	1[illegible].85
42		$Na_2HPO_4 + 12H_2O$	358.14	2.79	42.1^{0}	525^{30}	5.58	128	Na^+	5.58	268/86.5	HPO_4^{--} / P	8.3[illegible]
43	salicylate	$Na(C_7H_5O_3)$	160.11	6.25	1110^{15}	1250^{25}	6.25	144	Na^+	6.25	856	$C_7H_5O_3^-$	12.4[illegible]
44	sulphate (anhydrous)	Na_2SO_4	142.04	7.04	488^{40}	425^{100}	14.08	324	Na^+	14.08	676/226	SO_4^{--} / S	21.12
45	sulphate (Glauber's salt)	$Na_2SO_4 + 10H_2O$	322.19	3.10	113^{0}	925^{30}	6.21	143	Na^+	6.21	298/100	SO_4^{--} / S	9.31
46	thiosulphate	$Na_2S_2O_3$	158.11	6.32	525^{0}	2660^{100}	12.65	291	Na^+	12.65	709/406	$S_2O_3^{--}$ / S	1[illegible]
	Sulphur (S)												
	See Calcium (**11**), Magnesium (**18**) and Sodium (**44–46**)												

† The index figures are the temperatures in °C; v.s. = very soluble; d = decomposes.

†† On the assumption of complete dissociation.

* The oxides have been included in view of the continuing use of the older [illegible] tables.

** The sodium content of 1 g sodium bicarbonate corresponds to that of 1.33 g sodium lactate. The sodium content of 1 g sodium lactate corresponds to that of 0.75 g sodium bicarbonate.

No.	Electrolyte (data for 10 mosm of solute* unless otherwise stated)		Undissociated solute g	mmol	Cation mEq	mg		Anion mEq	mg	
	Calcium (Ca)									
1	acetate	$Ca(C_2H_3O_2)_2 + H_2O$	0 587	3⅓	6⅔	134	Ca^{++}	6⅔	394	$C_2H_3O_2^-$
2		$Ca(C_2H_3O_2)_2 + 2\,H_2O$	0 647	3⅓	6⅔	134	Ca^{++}	6⅔	394	$C_2H_3O_2^-$
3	chloride	$CaCl_2 + 2\,H_2O$	0 490	3⅓	6⅔	134	Ca^{++}	6⅔	236	Cl^-
4		$CaCl_2 + 6\,H_2O$	0 730	3⅓	6⅔	134	Ca^{++}	6⅔	236	Cl^-
5	citrate	$Ca_3(C_6H_5O_7)_2 + 4\,H_2O$	1 141	2	12	240	Ca^{++}	12	756	$C_6H_5O_7^{---}$
6	D gluconate	$Ca(C_6H_{11}O_7)_2 + H_2O$	1 495	3⅓	6⅔	134	Ca^{++}	6⅔	1301	$C_6H_{11}O_7^-$
7	lactate	$Ca(C_3H_5O_3)_2 + 5\,H_2O$	1 028	3⅓	6⅔	134	Ca^{++}	6⅔	594	$C_3H_5O_3^-$
8	laevulinate	$Ca(C_5H_7O_3)_2 + 2\,H_2O$	1 021	3⅓	6⅔	134	Ca^{++}	6⅔	767	$C_5H_7O_3^-$
0	phosphate, dibasic	$CaHPO_4 + 2\,H_2O$	0 860	5	10	200	Ca^{++}	10	480	HPO_4^{--}
									155	P
1	thiosulphate	$CaS_2O_3 + 6\,H_2O$	1 302	5	10	200	Ca^{++}	10	561	$S_2O_3^{--}$
									321	S
	Chlorine (Cl)									
2	Ammonium chloride	NH_4Cl	0 267	5	5	90	NH_4^+	5	177	Cl^-
3	Hydrochloric acid (10% solution)									
	1 g	(0 1 g HCl/g)	1 823	5	5	5	H^+	5	177	Cl^-
	1 ml	(0 1047 g HCl/ml)	1 741	5	5	5	H^+	5	177	Cl^-
	See also Calcium (3, 4), Magnesium (14, 15), Potassium (22) and Sodium (35)									
	Magnesium (Mg)									
14	chloride	$MgCl_2$	0 317	3⅓	6⅔	81	Mg^{++}	6⅔	236	Cl^-
15		$MgCl_2 + 6\,H_2O$	0 678	3⅓	6⅔	81	Mg^{++}	6⅔	236	Cl^-
18	sulphate	$MgSO_4 + 7\,H_2O$	1 232	5	10	122	Mg^{++}	10	480	SO_4^{--}
									160	S
	Phosphorus (P)									
	See Calcium (10), Potassium (26, 27) and Sodium (30, 31, 40–42)									
	Potassium (K)									
19	acetate	$K(C_2H_3O_2)$	0 491	5	5	196	K^+	5	295	$C_2H_3O_2^-$
20	bicarbonate	$KHCO_3$	0 501	5	5	196	K^+	5	305	HCO_3^-
21	bromide	KBr	0 595	5	5	196	K^+	5	400	Br^-
22	chloride	KCl	0 373	5	5	196	K^+	5	177	Cl^-
23	citrate	$K_3(C_6H_5O_7) + H_2O$	0 811	2½	7½	293	K^+	7½	473	$C_6H_5O_7^{---}$
24	D-gluconate	$K(C_6H_{11}O_7)$	1 171	5	5	196	K^+	5	976	$C_6H_{11}O_7^-$
26	phosphate, monobasic	KH_2PO_4	0 454	3⅓	3⅓	130	K^+	6⅔	320	HPO_4^{--}
									103	P
27	phosphate, dibasic	K_2HPO_4	0 581	3⅓	6⅔	261	K^+	6⅔	320	HPO_4^{--}
									103	P
	Sodium (Na)									
28	acetate	$Na(C_2H_3O_2) + 3\,H_2O$	0 680	5	5	115	Na^+	5	295	$C_2H_3O_2^-$
29	acid citrate	$Na_2H(C_6H_5O_7) + 1\tfrac{1}{2}\,H_2O$	0 658	2½	5	115	Na^+	7½	473	$C_6H_5O_7^{---}$
30	acid phosphate	$NaH_2PO_4 + H_2O$	0 460	3⅓	3⅓	77	Na^+	6⅔	320	HPO_4^{--}
31		$NaH_2PO_4 + 2\,H_2O$	0 520	3⅓	3⅓	77	Na^+	6⅔	320	HPO_4^{--}
									103	P
32	aminosalicylate	$Na(C_7H_6O_3N) + 2\,H_2O$	1 056	5	5	115	Na^+	5	761	$C_7H_6O_3N^-$
33	bicarbonate	$NaHCO_3$	0 420	5	5	115	Na^+	5	305	HCO_3^-
34	bromide	$NaBr$	0 514	5	5	115	Na^+	5	400	Br^-
35	chloride	$NaCl$	0 292	5	5	115	Na^+	5	177	Cl^-
36	citrate	$Na_3(C_6H_5O_7) + 2\,H_2O$	0 735	2½	7½	172	Na^+	7½	473	$C_6H_5O_7^{---}$
37		$Na_3(C_6H_5O_7) + 5\tfrac{1}{2}\,H_2O$	0 893	2½	7½	172	Na^+	7½	473	$C_6H_5O_7^{---}$
38	lactate	$Na(C_3H_5O_3)$	0 560	5	5	115	Na^+	5	445	$C_3H_5O_3^-$
40	phosphate	Na_2HPO_4	0 473	3⅓	6⅔	153	Na^+	6⅔	320	HPO_4^{--}
									103	P
41		$Na_2HPO_4 + 2\,H_2O$	0 593	3⅓	6⅔	153	Na^+	6⅔	320	HPO_4^{--}
									103	P
42		$Na_2HPO_4 + 12\,H_2O$	1 194	3⅓	6⅔	153	Na^+	6⅔	320	HPO_4^{--}
									103	P
43	salicylate	$Na(C_7H_5O_3)$	0 801	5	5	115	Na^+	5	686	$C_7H_5O_3^-$
44	sulphate (anhydrous)	Na_2SO_4	0 473	3⅓	6⅔	153	Na^+	6⅔	320	SO_4^{--}
									107	S
45	sulphate	$Na_2SO_4 + 10\,H_2O$	1 074	3⅓	6⅔	153	Na^+	6⅔	320	SO_4^{--}
									107	S
46	thiosulphate	$Na_2S_2O_3$	0 527	3⅓	6⅔	153	Na^+	6⅔	374	$S_2O_3^{--}$
									214	S
	Sulphur (S)									
	See Calcium (11), Magnesium (18) and Sodium (44–46)									

* On the assumption of complete dissociation

Aqueous Solutions – Conversion Factors for Electrolytes (III)

Left-hand column: Given: weight of the inorganic ions. Required: corresponding weight of the salt.
Right-hand column: Given: milliequivalents of the ions. Required: corresponding weight of the salt.

No.	Inorganic Ions			
1	**1 g = 49.90 mEq Calcium (Ca^{++}) corresponds to**		**1 mEq = 20.04 mg Calcium (Ca^{++}) corresponds to**	
2	4.396 g Calcium acetate	$Ca(C_2H_3O_2)_2 + H_2O$	88.09 mg Calcium acetate	$Ca(C_2H_3O_2)_2$
3	4.845 g Calcium acetate dihydrate	$Ca(C_2H_3O_2)_2 + 2\,H_2O$	97.10 mg Calcium acetate dihydrate	$Ca(C_2H_3O_2)_2$
4	3.668 g Calcium chloride	$CaCl_2 + 2\,H_2O$	73.51 mg Calcium chloride	$CaCl_2 + 2\,H_2O$
5	5.466 g Calcium chloride hexahydrate	$CaCl_2 + 6\,H_2O$	109.54 mg Calcium chloride hexahydrate	$CaCl_2 + 6\,H_2O$
6	4.745 g Calcium citrate	$Ca_3(C_6H_5O_7)_2 + 4\,H_2O$	95.08 mg Calcium citrate	$Ca_3(C_6H_5O_7)_2$
7	11.188 g Calcium D-gluconate	$Ca(C_6H_{11}O_7)_2 + H_2O$	224.20 mg Calcium D-gluconate	$Ca(C_6H_{11}O_7)_2$
8	7.692 g Calcium lactate	$Ca(C_3H_5O_3)_2 + 5\,H_2O$	154.15 mg Calcium lactate	$Ca(C_3H_5O_3)_2 +$
9	7.643 g Calcium laevulinate	$Ca(C_5H_7O_3)_2 + 2H_2O$	153.17 mg Calcium laevulinate	$Ca(C_5H_7O_3)_2 +$
11	4.294 g Calcium phosphate, dibasic	$CaHPO_4 + 2\,H_2O$	86.05 mg Calcium phosphate, dibasic	$CaHPO_4 + 2\,H$
12	6.495 g Calcium thiosulphate	$CaS_2O_3 + 6\,H_2O$	130.15 mg Calcium thiosulphate	$CaS_2O_3 + 6\,H_2$
	1 g Carbon dioxide (CO_2) corresponds to 1.387 g = 22.72 mEq bicarbonate ions (HCO_3^-)		**1 mEq = 61.02 mg Bicarbonate ions (HCO_3^-)** corresponds t 44.01 mg carbon dioxide (CO_2)	
	1 vol% Carbon dioxide (CO_2) at 0 °C and 760 mm Hg corresponds to 27.41 mg/l = 0.449 mEq/l bicarbonate ions (HCO_3^-)*		**1 mEq/l = 61.02 mg/l** *Bicarbonate ions (HCO_3^-)* correspond 0 °C and 760 mm Hg to 2.23 vol% carbon dioxide (CO_2)*	
13	**1 g = 28.21 mEq Chloride (Cl^-) corresponds to**		**1 mEq = 35.453 mg Chloride (Cl^-) corresponds to**	
14	1.509 g Ammonium chloride	NH_4Cl	53.49 mg Ammonium chloride	NH_4Cl
4	2.073 g Calcium chloride	$CaCl_2 + 2\,H_2O$	73.51 mg Calcium chloride	$CaCl_2 + 2\,H_2O$
5	3.090 g Calcium chloride hexahydrate	$CaCl_2 + 6\,H_2O$	109.55 mg Calcium chloride hexahydrate	$CaCl_2 + 6\,H_2O$
15	10.28 g or 9.823 ml Hydrochloric acid 10%		364.6 mg or 348.24 µl Hydrochloric acid 10%	
17	1.343 g Magnesium chloride	$MgCl_2$	47.61 mg Magnesium chloride	$MgCl_2$
18	2.867 g Magnesium chloride hexahydrate	$MgCl_2 + 6\,H_2O$	101.66 mg Magnesium chloride hexahydrate	$MgCl_2 + 6\,H_2O$
27	2.103 g Potassium chloride	KCl	74.56 mg Potassium chloride	KCl
41	1.648 g Sodium chloride	$NaCl$	58.44 mg Sodium chloride	$NaCl$
16	**1 g = 82.3 mEq Magnesium (Mg^{++}) corresponds to**		**1 mEq = 12.15 mg Magnesium (Mg^{++}) corresponds to**	
17	3.917 g Magnesium chloride	$MgCl_2$	47.61 mg Magnesium chloride	$MgCl_2$
18	8.364 g Magnesium chloride hexahydrate	$MgCl_2 + 6\,H_2O$	101.65 mg Magnesium chloride hexahydrate	$MgCl_2 + 6\,H_2O$
21	10.138 g Magnesium sulphate	$MgSO_4 + 7\,H_2O$	123.24 mg Magnesium sulphate	$MgSO_4 + 7\,H_2O$
22	**1 g Phosphorus (P)** *corresponds to*		At pH 4.3 **1 g Phosphorus (P)** *corresponds* to 32.28 mEq $H_2PO_4^-$ ions, and **1 mEq $H_2PO_4^-$** ions corresponds to 30.97 m phosphorus (with only a small error these figures can be used f	
11	5.556 g Calcium phosphate, dibasic	$CaHPO_4 + 2\,H_2O$	At pH 9.6 **1 g Phosphorus (P)** corresponds to 64.57 mEq HPO_4^{--} *ions*, and **1 mEq HPO_4^{--}** *ions corresponds* to 15.49 m phosphorus.	
31	4.394 g *Potassium phosphate, monobasic*	KH_2PO_4		
32	5.624 g Potassium phosphate, dibasic	K_2HPO_4		
36	4.455 g Sodium acid phosphate	$NaH_2PO_4 + H_2O$		
37	•5.037 g Sodium acid phosphate dihydrate	$NaH_2PO_4 + 2\,H_2O$		
46	4.583 g Sodium phosphate	Na_2HPO_4	At pH 7.4 and 38 °C 1 g *Phosphorus corresponds* to 58.1 mEq ions, and **1 mEq Phosphate** ions corresponds to 17.2 mg phosp 20% $H_2PO_4^-$ ions and ca. 80% HPO_4^{--} *ions*).	
47	5.746 g Sodium phosphate dihydrate	$Na_2HPO_4 + 2\,H_2O$		
48	11.563 g Sodium phosphate dodecahydrate	$Na_2HPO_4 + 12\,H_2O$		
23	**1 g = 25.57 mEq Potassium (K^+)** *corresponds to*		**1 mEq = 39.10** *mg* **Potassium (K^+)** *corresponds to*	
24	2.510 g Potassium acetate	$K(C_2H_3O_2)$	98.15 mg Potassium acetate	$K(C_2H_3O_2)$
25	2.560 g Potassium bicarbonate	$KHCO_3$	100.12 mg Potassium bicarbonate	$KHCO_3$
26	3.044 g Potassium bromide	KBr	119.01 mg Potassium bromide	KBr
27	1.907 g Potassium chloride	KCl	74.56 mg Potassium chloride	KCl
28	2.766 g Potassium citrate	$K_3(C_6H_5O_7) + H_2O$	108.14 mg Potassium citrate	$K_3(C_6H_5O_7) + H_2$
29	5.991 g Potassium D-gluconate	$K(C_6H_{11}O_7)$	234.25 mg Potassium D-gluconate	$K(C_6H_{11}O_7)$
31	3.480 g Potassium phosphate, monobasic	KH_2PO_4	136.09 mg Potassium phosphate, monobasic	KH_2PO_4
32	2.227 g Potassium phosphate, dibasic	K_2HPO_4	87.09 mg Potassium phosphate, dibasic	K_2HPO_4
33	**1 g = 43.50 mEq Sodium (Na^+)** *corresponds to*		**1 mEq = 22.99** *mg* **Sodium (Na^+)** *corresponds to*	
34	5.919 g Sodium acetate	$Na(C_2H_3O_2) + 3\,H_2O$	136.08 mg Sodium acetate	$Na(C_2H_3O_2) + 3\,H$
35	5.722 g Sodium acid citrate	$Na_2H(C_6H_5O_7) + 1\tfrac{1}{2}\,H_2O$	131.56 mg Sodium acid citrate	$Na_2H(C_6H_5O_7) + 1$
36	6.002 g Sodium acid phosphate	$NaH_2PO_4 + H_2O$	137.99 mg Sodium acid phosphate	$NaH_2PO_4 + H_2O$
37	6.786 g Sodium acid phosphate dihydrate	$NaH_2PO_4 + 2\,H_2O$	156.01 mg Sodium acid phosphate dihydrate	$NaH_2PO_4 + 2\,H_2O$
38	9.185 g Sodium aminosalicylate	$Na(C_7H_6O_3N) + 2\,H_2O$	211.15 mg Sodium aminosalicylate	$Na(C_7H_6O_3N) + 2$
39	3.654 g Sodium bicarbonate	$NaHCO_3$	84.01 mg Sodium bicarbonate	$NaHCO_3$
41	2.542 g Sodium chloride	$NaCl$	58.44 mg Sodium chloride	$NaCl$
42	4.264 g Sodium citrate	$Na_3(C_6H_5O_7) + 2\,H_2O$	98.03 mg Sodium citrate	$Na_3(C_6H_5O_7) + 2\,H$
43	5.178 g Sodium citrate	$Na_3(C_6H_5O_7) + 5\tfrac{1}{2}\,H_2O$	119.05 mg Sodium citrate	$Na_3(C_6H_5O_7) + 5\tfrac{1}{2}$
44	4.874 g Sodium lactate	$Na(C_3H_5O_3)$	112.06 mg Sodium lactate	$Na(C_3H_5O_3)$
46	3.087 g Sodium phosphate	Na_2HPO_4	70.98 mg Sodium phosphate	Na_2HPO_4
47	3.781 g Sodium phosphate dihydrate	$Na_2HPO_4 + 2\,H_2O$	88.99 mg Sodium phosphate dihydrate	$Na_2HPO_4 + 2\,H_2O$
48	7.789 g Sodium phosphate dodecahydrate	$Na_2HPO_4 + 12\,H_2O$	179.07 mg Sodium phosphate dodecahydrate	$Na_2HPO_4 + 12\,H_2C$
49	6.964 g Sodium salicylate	$Na(C_7H_5O_3)$	160.11 mg Sodium salicylate	$Na(C_7H_5O_3)$
50	3.089 g Sodium sulphate (anhydrous)	Na_2SO_4	71.02 mg Sodium sulphate (anhydrous)	Na_2SO_4
51	7.007 g Sodium sulphate	$Na_2SO_4 + 10\,H_2O$	161.10 mg Sodium sulphate	$Na_2SO_4 + 10\,H_2O$
52	3.439 g Sodium thiosulphate	$Na_2S_2O_3$	79.05 mg Sodium thiosulphate	$Na_2S_2O_3$
53	**1 g Sulphur (S) corresponds to**		**1 g Sulphur (S)** corresponds to 62.37 mEq SO_4^{--} ions and **1 mEq** ions corresponds to 16.03 mg sulphur.	
12	4.059 g Calcium thiosulphate	$CaS_2O_3 + 6\,H_2O$	At pH 7.4 and 38 °C and with an albumin/globulin ratio of 1.6, serum proteins corresponds to *0.241 basic mEq* of ionized seru teins, and **1 mEq** of ionized serum proteins corresponds to 4.1 serum proteins[1].	
21	7.687 g Magnesium sulphate	$MgSO_4 + 7\,H_2O$		
50	4.430 g *Sodium sulphate (anhydrous)*	Na_2SO_4		
51	10.048 g Sodium sulphate	$Na_2SO_4 + 10\,H_2O$		
52	2.465 g Sodium thiosulphate	$Na_2S_2O_3$		

* The conversion factors (0.449 and 2.23) given here for vol% CO_2 into mmol CO_2/l and mEq CO_2/l (bicarbonate-CO_2) are derived from the molar volume of this gas (22.257 l at 0 °C and 760 mm Hg). The conversion factor 2.24 often used in medical literature is mistakenly based on the molar volume of ideal gases (22.414 l). For practical purposes the difference bet these two factors is negligible.

[1] From VAN SLYKE et al., *J. biol. Chem.*, 79, 768 (1928).

Name	Molecular weight	Hydrogen equivalent	1 l of 0.1 N solution contains (gramme)	Mantissa of $\log_{10}$ of equivalent weight*
Acetic acid	60.05	$C_2H_4O_2$	6.005	7785
Ammonia	17.03	NH_3	1.703	2312
Ammonium chloride	53.49	NH_4Cl	5.349	7283
Ammonium hydroxide	35.05	NH_4OH	3.505	5447
Ammonium nitrate	80.04	NH_4NO_3	8.004	9033
Ammonium sulphate	132.14	$^1/_2\,(NH_4)_2SO_4$	6.607	8200
Ammonium thiocyanate	76.12	NH_4CNS	7.612	8815
Barium carbonate	197.35	$^1/_2\,BaCO_3$	9.868	9942
Barium chloride	244.28	$^1/_2\,[BaCl_2 + 2H_2O]$	12.214	0869
Barium hydroxide	315.48	$^1/_2\,[Ba(OH)_2 + 8H_2O]$	15.774	1979
Barium oxide	153.34	$^1/_2\,BaO$	7.667	8846
Borax. See Sodium tetraborate decahydrate				
Boric acid	61.83	$^1/_3\,H_3BO_3$	2.061	3141
Bromine	159.81	$^1/_2\,Br_2$	7.991	9026
Calcium carbonate	100.09	$^1/_2\,CaCO_3$	5.005	6994
Calcium chloride	110.99	$^1/_2\,CaCl_2$	5.550	7443
Calcium chloride hexahydrate	219.08	$^1/_2\,[CaCl_2 + 6H_2O]$	10.954	0396
Calcium hydroxide	74.09	$^1/_2\,Ca(OH)_2$	3.705	5688
Calcium oxide	56.08	$^1/_2\,CaO$	2.804	4478
Carbon dioxide	44.01	$^1/_2\,CO_2$	2.201	3426
Chlorine	70.91	$^1/_2\,Cl_2$	3.546	5497
Citric acid	210.14	$^1/_3\,[C_6H_8O_7 + H_2O]$	7.005	8454
Copper oxide	79.55	$^1/_2\,CuO$	3.978	5997
Copper sulphate	249.68	$^1/_2\,[CuSO_4 + 5H_2O]$	12.484	0964
Hydriodic acid	127.91	HI	12.791	1069
Hydrobromic acid	80.91	HBr	8.091	9080
Hydrochloric acid	36.46	HCl	3.646	5618
Hydrocyanic acid	27.03	HCN	2.703	4318
Iodine	253.81	$^1/_2\,I_2$	12.691	1035
Lactic acid	90.08	$C_3H_6O_3$	9.008	9546
Lead carbonate	267.20	$^1/_2\,PbCO_3$	13.360	1258
Lead oxide	223.19	$^1/_2\,PbO$	11.160	0477
Magnesium carbonate	84.31	$^1/_2\,MgCO_3$	4.216	6249
Magnesium chloride	95.21	$^1/_2\,MgCl_2$	4.761	6777
Magnesium chloride hexahydrate	*203.30*	$^1/_2\,[MgCl_2 + 6H_2O]$	*10.165*	0071_5
Magnesium oxide	40.31	$^1/_2\,MgO$	2.016	3045
Malic acid	134.09	$^1/_2\,C_4H_6O_5$	6.705	8264
Manganese sulphate	151.00	$^1/_2\,MnSO_4$	7.550	8779
Mercuric chloride (corrosive sublimate)	271.50	$^1/_2\,HgCl_2$	13.575	1327
Nitric acid	63.01	HNO_3	6.301	7994
Nitrous acid	47.01	HNO_2	4.701	6722
Oxalic acid	90.04	$^1/_2\,C_2H_2O_4$	4.502	6534
Oxalic acid dihydrate	126.07	$^1/_2\,[C_2H_2O_4 + 2H_2O]$	6.304	7996
Phosphoric acid	98.00	$^1/_3\,H_3PO_4$	3.267	5141
Potassium bicarbonate	100.12	$KHCO_3$	10.012	0005_3
Potassium bitartrate	188.18	$C_4H_5O_6K$	18.818	2746
Potassium carbonate	138.21	$^1/_2\,K_2CO_3$	6.911	8395
Potassium chloride	74.56	KCl	7.456	8725
Potassium cyanide	65.12	KCN	6.512	8137
Potassium dichromate	294.19	$^1/_6\,K_2Cr_2O_7$	4.903	6905
Potassium hydroxide	56.11	KOH	5.611	7490
Potassium oxide	94.20	$^1/_2\,K_2O$	4.710	6730
Potassium permanganate in acid medium	158.04	$^1/_5\,KMnO_4$	3.161	4998
Potassium permanganate for Mn determination	158.04	$^1/_3\,KMnO_4$	5.268	7216
Potassium tartrate	226.28	$^1/_2\,C_4H_4O_6K_2$	11.314	0536
Potassium tetroxalate	254.20	$^1/_3\,[KH_3(C_2O_4)_2 + 2H_2O]$	8.473	9280
Silver nitrate	169.87	$AgNO_3$	16.987	2301
Sodium bicarbonate	84.01	$NaHCO_3$	8.401	9243
Sodium carbonate	105.99	$^1/_2\,Na_2CO_3$	5.300	7243
Sodium chloride	58.44	$NaCl$	5.844	7667
Sodium hydroxide	40.00	$NaOH$	4.000	6021
Sodium oxide	61.98	$^1/_2\,Na_2O$	3.099	4912
Sodium phosphate (disodium phosphate)	177.99	$^1/_2\,[Na_2HPO_4 + 2H_2O]$	8.900	9494
Sodium phosphate (trisodium phosphate)	380.12	$^1/_3\,[Na_3PO_4 + 12H_2O]$	12.671	1028
Sodium sulphide	78.04	$^1/_2\,Na_2S$	3.902	5913
Sodium tetraborate	201.22	$^1/_2\,Na_2B_4O_7$	10.061	0026_4
Sodium tetraborate decahydrate (borax)	381.37	$^1/_2\,[Na_2B_4O_7 + 10H_2O]$	19.069	2803
Succinic acid	118.09	$^1/_2\,C_4H_6O_4$	5.905	7712
Sulphuric acid	98.08	$^1/_2\,H_2SO_4$	4.904	6906
Sulphur trioxide	80.06	$^1/_2\,SO_3$	4.003	6024
Tartaric acid	150.09	$^1/_2\,C_4H_6O_6$	7.505	8754
Zinc sulphate	287.54	$^1/_2\,[ZnSO_4 + 7H_2O]$	14.377	1577

* For logarithms see page 10

Definitions of pH scales[1,2]

A. Dissociation constant of water

The relationship between the concentrations of hydrogen ions* and hydroxyl ions in an aqueous medium is fixed by the dissociation equilibrium of water:

$$H_2O \rightleftharpoons H^+ + OH^- \quad (1)$$

If solutes are present in such small concentrations that the activity of water is practically unity**, the ion product constant*** of water is given by

$$K_W = a_H a_{OH} = m_H \gamma_H m_{OH} \gamma_{OH} \quad (2)$$

where a = ionic activity, γ = activity coefficient, m = molality.

The dissociation of pure water is extremely small***, and if no solutes are present

$$\gamma_H = \gamma_{OH} \approx 1 \quad (3)$$

Since the value of K_W at 25 °C is 1.008×10^{-14} it follows that for pure water

$$m_H = m_{OH} = \sqrt{K_W} \simeq 1 \times 10^{-7} \quad (4)$$

In water the molarity c of the ions is practically identical with the molality m (see page 271), so that for pure water

$$c_H \simeq m_H \simeq 1 \times 10^{-7} \quad (5)$$

In aqueous solutions the solutes may give rise to additional H^+ ions (dissociation of acids, hydrolysis of salts, etc.), with the result that the equilibrium (1) is displaced and the concentration of OH^- ions reduced. In the same way additional OH^- ions cause a decrease in the concentration of H^+ ions, so that $c_H \leqslant 1 \times 10^{-7}$. In the former case the solution is said to be 'acid', in the latter 'alkaline'. Since the ion product constant K_W is markedly temperature-dependent the same applies to the neutral point of c_H, the value of which at 0 °C is $1 \times 10^{-7.5}$, at 60 °C $1 \times 10^{-6.5}$.

Temperature dependence of the ion product constant of water (K_W)[3]

°C	$K_w \times 10^{14}$	$-\log K_w$	°C	$K_w \times 10^{14}$	$-\log K_w$
0	0.1139	14.943	35	2.089	13.680
5	0.1846	14.734	40	2.919	13.535
10	0.2920	14.535	45	4.018	13.396
15	0.4505	14.346	50	5.474	13.262
20	0.6809	14.167	55	7.297	13.137
25	1.008	13.996	60	9.614	13.017
30	1.469	13.833			

B. The Sorensen pH scale

Sorensen was the first to realize the importance of hydrogen ion concentration in biochemical processes, and he devised colorimetric and potentiometric methods of measuring quantities which – in the light of the thermodynamic concepts of the time (1909) – were considered as strictly equal to the molarity of the hydrogen ion. At the same time he introduced the abbreviation now written as pH:

$$pH = -\log_{10} c_H \quad (6)$$

As the actual means of measuring pH, Sorensen chose the cell

$$\text{Pt; } H_2\text{, Solution } X \left| \begin{matrix}\text{KCl bridge}\\ \textit{solution}^{\dagger}\end{matrix} \right| \text{0.1-N Calomel electrode} \quad (7)$$

the e.m.f. of which (E) is compared with that (E') of a simi[lar cell] containing a solution†† of $c_H = 1$ in place of the solution. [For] this purpose the hydrogen electrode could be replaced b[y an]other electrode responsive to H^+ ions (a quinhydrone o[r glass] electrode for instance). Other reference electrodes could li[kewise] be used in place of the calomel electrode. It is necessary on[ly that] the comparison be made under the same conditions, such a[s con]stancy of temperature. According to Sorensen, the pH va[lue of] the solution X is given by

$$pH_{Sorensen} = \frac{(E - E')F}{RT \ln 10}$$

where F is the Faraday constant, R the molar gas constant, [T the] absolute temperature, and $\ln 10 = 2.30259$. Values of $(RT \ln$[$10)/F$] at various temperatures are given on the opposite page.

C. The conventional pH scale

It is now known that the e.m.f. of the cell (7) is dependen[t not] only on the concentration of H^+ ions but also on their activit[y, on] the activity of the Cl^- ions, and on the transference numbers o[f the] ions (variation of the diffusion potential with ionic concentrati[on). For] this reason comparison is no longer made with a refer[ence] solution whose c_H value is assumed to be unity but with a stand[ard] solution S whose pH value (pH_S) is fixed by convention. The [pH] value of the solution X is then defined conventionally as

$$pH_X = \frac{(E_X - E_S)F}{RT \ln 10} + pH_S$$

In the United Kingdom[4] and Japan[5] the primary standard s[o]lution is 1/20-molar potassium hydrogen phthalate, while in t[he] USA[6] five standard solutions are in use (all these standards a[re] the same conventions). The five US standard solutions ha[ve] assigned pH_S values between 3.5 and 9.5. This allows of an alter[]native definition of pH through comparison of the solution X w[ith] two standards S and S', when pH_X is obtained from the follow[ing] formula:

$$\frac{pH_X - pH_S}{pH_{S'} - pH_S} = \frac{E - E_S}{E_{S'} - E_S}$$

This procedure is especially recommended when the H^+-[] responsive electrode is a glass electrode. Differences in meas[ured] values of pH obtained by the use of different standard sol[utions] are too small to be of practical significance.

Values of pH on the Sorensen and conventional scales di[ffer by] a constant amount as follows[2]:

$$pH = pH_{Sorensen} + 0.04$$

D. Thermodynamic interpretation of the conventional pH scale

It is clear from the above that there exists no definite re[lation]ship between the conventional pH scale and any true the[rmo]dynamic measurement of the acidity of a solution such as H^+ [ion] molality (m_H). This scale meets all practical needs, howev[er, so] that there is little value in introducing more complicated me[thods] of measurement for the sake of thermodynamic principle[s. The] difficulty lies in the fact that while only the product $\gamma_c \gamma_a$ [of the] activity coefficients of the cation and anion has any clear the[rmo]dynamic meaning, this is a quantity which cannot be measur[ed by] means of arrangements like the cell (7). The difficulty has b[een] overcome by defining the activity of the *chloride* ion by

$$\log \gamma_{Cl} = -\frac{A\sqrt{I}}{1 + B'\sqrt{I}}$$

where A is the Debye-Hückel constant[7] $= 1.82 \times 10^{6}$[] (ε = dielectric constant of the solution), B' a constant dep[ending] on the finite size of the ion, and I the ionic strength (not ex[ceeding] 0.1) defined as $\frac{1}{2}\sum_i m_i z_i^2$ for all the ionic species present. O[n the] basis of this equation it can be assumed that for solutions w[ith] ionic strength less than 0.1 and pH values between 2 and 1[2]

$$pH = -\log(m_H \gamma_H) = -\log a_H$$

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* For the sake of simplicity the expressions hydrogen ion and hydroxyl ion [ar]e here used, although these ions never occur in the free state but only [as]sociated with water molecules (mainly in the form of $H_9O_4^+$ and $H_7O_4^-$).

** The activity of water in an aqueous solution is $p/p°$, where p and $p°$ [ar]e the pressures of water vapour in equilibrium respectively with the solution [an]d with pure water at the temperature in question, provided that p and $p°$ [ar]e so small that water vapour can be considered an ideal gas[2].

*** The dissociation constant of water, rarely to be found in the literature, [is] given by K_W/m_{H_2O}, the value of m_{H_2O} being 55.51.

† The KCl solution is usually contained in a tube connecting the two halves [of] the cell and prevented from mixing with the other two solutions by means [of] agar plugs. Diffusion potentials arise at the two liquid junctions but these [ar]e of opposite sign and almost equal because of the similar transference num[b]ers of the K^+ and Cl^- ions. Sorensen originally attempted to measure E [fo]r various concentrations of the KCl bridge and to extrapolate to a zero [di]ffusion potential. Under the present convention, the KCl bridge must have [a concentration] of at least 3.5-N (saturated KCl is 4.2-N) maintained con-

†† Sorensen used HCl with a correction based on conductivit[y]

…es of $(RT\ \ln 10)/F$ from 0° to 100 °C*[2]

°C	$RT \ln 10/F$	°C	$RT \ln 10/F$
0	0 054197	50	0 064118
5	0 055189	55	0 065110
10	0 056181	60	0 066102
15	0 057173	65	0 067094
20	0 058165	70	0 068086
25	0 059157	75	0 069078
30	0 060149	80	0 070070
35	0 061141	85	0 071062
38	0 061737	90	0 072054
40	0 062133	95	0 073046
45	0 063126	100	0 074038

ln10 = 2.30259, R = 8 3143 J mol⁻¹ deg⁻¹, F = 96 487 0 C mol⁻¹,
= °C + 273 15.

values of standard solutions at 25 °C on different scales[2]

Solution	Scale of Hitchcock and Taylor	MacInnes et al	National Bureau of Standards
…otassium bitartrate, 0 03-molar	3 567	–	3 569
…otassium biphthalate, 0 05-molar	4 010	4 000	4 008
…cetic acid 0 1-molar, Sodium acetate 0 1-molar.	4.645	4 640	4 652
…H_2PO_4 0 025-molar, NaH_2PO_4 0 025-molar	6.855	–	6 865
…odium tetraborate decahydrate 0 05-molar (borax)	9 180	–	9 196

…$_s$ values of NBS primary standards from 0° to 95 °C[2]

Temperature (°C)	Potassium bitartrate (saturated at 25 °C)	Potassium biphthalate 0 05-molal	KH_2PO_4, 0 025 molal Na_2HPO_4, 0 025 molal	KH_2PO_4, 0 008695 molal Na_2HPO_4, 0 03043-molal	Sodium tetraborate decahydrate (borax) 0 01 molal
0	–	4 003	6 984	7 534	9 464
5	–	3 999	6 951	7 500	9 395
10	–	3 998	6 923	7 472	9 332
15	–	3 999	6 900	7 448	9 276
20	–	4 002	6 881	7 429	9 225
25	3 557	4 008	6 865	7 413	9 180
30	3 552	4 015	6 853	7 400	9 139
35	3 549	4 024	6 844	7 389	9 102
38	3 548	4 030	6 840	7.384	9 081
40	3 547	4 035	6 838	7 380	9 068
45	3 547	4 047	6 834	7.373	9 038
50	3 549	4 060	6 833	7.367	9 011
55	3 554	4 075	6 834	–	8 985
60	3 560	4 091	6 836	–	8 962
70	3 580	4 126	6 845	–	8 921
80	3 609	4 164	6 859	–	8 885
90	3 650	4 205	6 877	–	8 850
95	3 674	4 227	6 886	–	8 833

pH values of secondary British standards[2]

Solution	12 °C	25 °C	38 °C
Potassium tetroxalate 0 1-molar	–	1 48	1.50
HCl 0 01-molar, KCl 0 09-molar	–	2 07	2.08
Acetic acid 0 1-molar, Sodium acetate 0 1-molar	4 65	4 64	4 65
Acetic acid 0 01-molar, Sodium acetate 0 01-molar	4 71	4 70	4 72
KH_2PO_4 0 025-molar, Na_2HPO_4 0 025-molar	–	6 85	6 84
Sodium tetraborate decahydrate (borax) 0 05-molar	–	9 18	9 07
$NaHCO_3$ 0 025-molar, Na_2CO_3 0 025-molar	–	10 00	–

Approximate pH values of common reagent solutions at or near room temperature[2]

Solution	Molarity	pH
Ammonia water	0 1	11.3
Ammonium chloride	0 1	4 6
Ammonium dihydrogen phosphate	0 1	4 0
Ammonium oxalate	0 1	6 4
Ammonium sulphate	0 1	5 5
Barbital sodium	0 1	9 4
Benzoic acid	saturated	2 8
Boric acid	0 1	5 3
Calcium hydroxide	saturated	12 4
Citric acid	0 1	2 1
Diammonium hydrogen phosphate	0 1	7.9
Disodium hydrogen phosphate	0 1	9 2
Hydrochloric acid	0 1	1.1
Oxalic acid	0 1	1.3
Potassium acetate	0 1	9 7
Potassium aluminium sulphate	0 1	4 2
Potassium bicarbonate	0 1	8 2
Potassium carbonate	0 1	11 5
Potassium dihydrogen phosphate	0 1	4 5
Salicylic acid	saturated	2 4
Sodium acetate	0 1	8 9
Sodium benzoate	0 1	8 0
Sodium bicarbonate	0 1	8 3
Sodium bisulphate	0 1	1 4
Sodium carbonate	0 1	11 5
Sodium dihydrogen phosphate	0 1	4 5
Sodium hydroxide	0 1	12 9
Sodium tetraborate decahydrate	0 1	9 4
Succinic acid	0 1	2 7
Tartaric acid	0 1	2 0
Trichloracetic acid	0 1	1 2

R

Buffer Solutions*

Buffer solutions (or buffers) are solutions whose pH value is to a large degree insensitive to the addition of other substances. It is important to realize, however, that the pH value of a buffer solution does not change only when acids or bases are added or on dilution but also when the temperature changes or neutral salts are added. In accurate work therefore, it is important to check the pH value electrometrically after all the ingredients have been added. The extent to which the pH values of buffer solutions vary when acids or bases are added or the temperature changes is shown in the tables which follow. In general, dilution to half the concentration changes the pH value by only some hundredths of a unit (Buffer No. 1 in the table is an exception in that the change amounts to ca. pH 0.15); addition of 0.1-molar neutral salt solution may change the pH value by ca. 0.1.

In the table opposite the solutions are classified into general buffers (mostly in use for the last 50 years), universal buffers with a low buffering capacity but a wide pH range, and buffers for biological media with a moderate pH range but containing stable ingred (phosphate and borate, for example, often undergo side react with biological media). An important property is often the tr parency to ultraviolet light. Occasionally it is desirable to ha volatile buffer which can be readily removed[1] (examples are bu Nos. 20 and 21) but the use of very volatile systems makes a c control of the pH essential. Most of the pH data to be found in literature relate to the Sorensen scale, and it should be noted t the values given in the following table of buffers are on the c ventional pH scale (cf. 'pH Standards', page 278).

Both stock and buffer solutions should be made up with disti water free of CO_2. Only standard reagents should be used. If th is any doubt as to the purity or water content of solutions th molarity must be checked by titration. The amounts x of sto solutions required to make up a buffer solution of the desired p value are given in the table on page 282.

* This section (pages 280–282) has been compiled by F. Kohler, Department of Physical Chemistry, University of Vienna.

Reference

[1] For a list of volatile buffers see Michl, H., in Heftmann, E. (Ed.), *Ch matography*, part 1, Reinhold, New York, 1961, page 250.

No.	Name	pH range	Temperature	pH change per °C
	General buffers			
1	KCl/HCl (Clark and Lubs)[1]	1.0– 2.2	Room	0
2	Glycine/HCl (Sorensen)[2]	1.2– 3.4	Room	0
3	Na citrate/HCl (Sorensen)[2]	1.2– 5.0	Room	0
4	K biphthalate/HCl (Clark and Lubs)[1]	2.4– 4.0	20 °C	+0.001
5	K biphthalate/NaOH (Clark and Lubs)[1]	4.2– 6.2	20 °C	
6	Na citrate/NaOH (Sorensen)[2]	5.2– 6.6	20 °C	+0.004
7	Phosphate (Sorensen)[2]	5.0– 8.0	20 °C	−0.003
8	Barbital-Na/HCl (Michaelis)[3]	7.0– 9.0	18 °C	
9	Na borate/HCl (Sorensen)[2]	7.8– 9.2	20 °C	−0.005
10	Glycine/NaOH (Sorensen)[2]	8.6–12.8	20 °C	−0.025
11	Na borate/NaOH (Sorensen)[2]	9.4–10.6	20 °C	−0.01
	Universal buffers			
12	Citric acid/phosphate (McIlvaine)[4]	2.2– 7.8	21 °C	
13	Citrate-phosphate-borate/HCl (Teorell and Stenhagen)[5]	2.0–12.0	20 °C	
14	Britton-Robinson[6]	2.6–11.8	25 °C	at low pH 0 at high pH −0.02
	Buffers for biological media			
15	Acetate (Walpole)[7–9]	3.8– 5.6	25 °C	
16	Dimethylglutaric acid/NaOH[10]	3.2– 7.6	21 °C	
17	Piperazine/HCl[11,12]	4.6– 6.4 8.8–10.6	20 °C	
18	Tetraethylethylenediamine*[12]	5.0– 6.8 8.2–10.0	20 °C	
19	Trismaleate[7,13]	5.2– 8.6	23 °C	
20	Dimethylaminoethylamine*[12]	5.6– 7.4 8.6–10.4	20 °C	
21	Imidazole/HCl[14]	6.2– 7.8	25 °C	
22	Triethanolamine/HCl[15]	7.0– 8.8	25 °C	
23	*N*-Dimethylaminoleucylglycine/NaOH[16]	7.0– 8.8	23 °C	−0.015
24	Tris/HCl[7]	7.2– 9.0	23 °C	−0.02
25	2-Amino-2-methylpropane-1,3-diol/HCl[7,13]	7.8–10.0	23 °C	
26	Carbonate (Delory and King)[7,17]	9.2–10.8	20 °C	

* Can be combined with tris buffer to give a cationic universal buffer (cf. Semenza et al.[12]).

References

[1] Clark and Lubs, *J. Bact.*, 2, 1 (1917).
[2] Sørensen, S.P.L., *Biochem. Z.*, 21, 131 (1909), and 22, 352 (1909); *Ergebn. Physiol.*, 12, 393 (1912); Walbum, L.E., *Biochem. Z.*, 107, 219 (1920).
[3] Michaelis, L., *J. biol. Chem.*, 87, 33 (1930).
[4] McIlvaine, T.C., *J. biol. Chem.*, 49, 183 (1921).
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[6] Britton and Welford, *J. chem. Soc.*, 1937, 1848.
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[16] Leonis, J., *C. R. Lab. Carlsberg, Sér. Chim.*, 26, 357 (1948).
[17] Delory and King, *Biochem. J.*, 39, 245 (1945).

en not otherwise specified, both stock and buffer solutions should be made up with distilled water free of CO_2. Only standard reagents should be used. If re is any doubt as to the purity or water content of solutions their molarity must be checked by titration. The amounts x of stock solutions required to make up a buffer solution of the desired pH value are given in the table on page 282.

uffer No	Stock solutions A	Stock solutions B	Composition of the buffer
1	KCl 0.2-N (14.91 g/l)	HCl 0.2-N	25 ml A + x ml B made up to 100 ml
2	Glycine 0.1-molar in NaCl 0.1-N (7.507 g glycine + 5.844 g NaCl/l)	HCl 0.1-N	x ml A + (100 − x) ml B
3	Disodium citrate 0.1-molar (21.01 g $C_6H_8O_7 \cdot 1H_2O$ + 200 ml NaOH 1-N per litre)	HCl 0.1-N	x ml A + (100 − x) ml B
4	Potassium biphthalate 0.1-molar (20.42 g $KHC_8H_4O_4$/l)	HCl 0.1-N	50 ml A + x ml B made up to 100 ml
5	As No 4	NaOH 0.1-N	50 ml A + x ml B made up to 100 ml
6	As No 3	NaOH 0.1-N	x ml A + (100 − x) ml B
7	Monopotassium phosphate $^1/_{15}$-molar (9.073 g KH_2PO_4/l)	Disodium phosphate $^1/_{15}$-molar (11.87 g $Na_2HPO_4 \cdot 2H_2O$/l)	x ml A + (100 − x) ml B
8	Barbital sodium 0.1-molar (20.62 g/l)	HCl 0.1-N	x ml A + (100 − x) ml B
9	Boric acid, half-neutralized, 0.2-molar (corr. to 0.05-molar borax, 12.37 g boric acid + 100 ml NaOH 1-N per litre)	HCl 0.1-N	x ml A + (100 − x) ml B
10	As No. 2	NaOH 0.1-N	x ml A + (100 − x) ml B
11	As No. 9	NaOH 0.1-N	x ml A + (100 − x) ml B
12	Citric acid 0.1-molar (21.01 g $C_6H_8O_7 \cdot 1H_2O$/l)	Disodium phosphate 0.2-molar (35.60 g $Na_2HPO_4 \cdot 2H_2O$/l)	x ml A + (100 − x) ml B
13	To citric acid and phosphoric acid solutions (ca. 100 ml), each equivalent to 100 ml NaOH 1-N, add 3.54 g cryst. orthoboric acid and 343 ml NaOH 1-N, and make up the mixture to 1 l	HCl 0.1-N	20 ml A + x ml B made up to 100 ml
14	Citric acid, monopotassium phosphate, barbital, boric acid, all 0.02857-molar (6.004 g $C_6H_8O_7 \cdot 1H_2O$, 3.888 g KH_2PO_4, 5.263 g barbital, 1.767 g H_3BO_3/l)	NaOH 0.2-N	100 ml A + x ml B
15	Sodium acetate 0.1-N (8.204 g $C_2H_3O_2Na$ or 13.61 g $C_2H_3O_2Na \cdot 3H_2O$/l)	Acetic acid 0.1-N (6.005 g/l)	x ml A + (100 − x) ml B
16	ββ-Dimethylglutaric acid 0.1-molar (16.02 g/l)	NaOH 0.2-N	(a) 100 ml A + x ml B made up to 1000 ml (b) 100 ml A + x ml B + 5.844 g NaCl made up to 1000 ml (NaCl ≙ 0.1-molar)
17	Piperazine 1-molar (86.14 g/l)	HCl 0.1-N	5 ml A + x ml B made up to 100 ml
18	Tetraethylethylenediamine 1-molar (172.32 g/l)	HCl 0.1-N	5 ml A + x ml B made up to 100 ml
19	Tris acid maleate 0.2-molar (24.23 g tris[hydroxymethyl]-aminomethane + 23.21 g maleic acid or 19.61 g maleic anhydride/l)	NaOH 0.2-N	25 ml A + x ml B made up to 100 ml
20	Dimethylaminoethylamine 1-molar (88 g/l)	HCl 0.1-N	5 ml A + x ml B made up to 100 ml
21	Imidazole 0.2 molar (13.62 g/l)	HCl 0.1-N	25 ml A + x ml B made up *to 100 ml*
22	Triethanolamine 0.5-molar (76.11 g/l) containing 20 g/l ethylenediaminetetra-acetic acid disodium salt ($C_{10}H_{14}O_8N_2Na_2 \cdot 2H_2O$)	HCl 0.05-N	10 ml A + x ml B made up to 100 ml
23	*N*-Dimethylaminoleucylglycine 0.1-molar (24.33 g $C_{11}H_{24}O_3N_4 \cdot {}^1/_2H_2O$/l) containing NaCl 0.2-N (11.69 g/l)	NaOH 1-N 100 ml made up to 1 l with A	x ml A + (100 − x) ml B

Buffer Solutions

The table gives the amounts (x ml) of the stock solutions listed on page 281 required to make up a buffer solution of the desired pH value

pH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16a	16b	17	18	19	20	21	22	23	24	25	26	pH
1.0	54.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1.0
1.2	36.0	11.1	9.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1.2
1.4	23.2	26.4	17.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1.4
1.6	14.7	36.2	23.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1.6
1.8	9.3	43.9	27.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1.8
2.0	5.9	50.7	30.2	...	...	...	...	...	...	...	...	...	74.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2.0
2.2	3.8	56.5	32.2	...	...	...	...	...	...	...	...	98.8	68.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2.2
2.4	...	62.3	34.1	41.0	...	...	...	...	...	...	...	94.5	64.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2.4
2.6	...	68.4	36.0	34.3	...	...	...	...	...	...	...	90.0	61.3	1.6	...	...	...	...	...	...	...	...	...	...	...	...	...	2.6
2.8	...	74.7	37.9	27.8	...	...	...	...	...	...	...	85.1	58.9	3.6	...	...	...	...	...	...	...	...	...	...	...	...	...	2.8
3.0	...	81.0	39.9	21.6	...	...	...	...	...	...	...	80.3	56.9	5.7	...	...	...	...	...	...	...	...	...	...	...	...	...	3.0
3.2	...	86.2	42.1	15.9	...	...	...	...	...	...	...	76.0	55.2	7.8	...	7.0	14.4	...	...	...	...	...	...	...	...	...	...	3.2
3.4	...	90.3	44.8	10.9	...	...	...	...	...	...	...	72.0	53.9	9.9	...	13.3	20.9	...	...	...	...	...	...	...	...	...	...	3.4
3.6	...	...	47.8	6.7	...	...	...	...	...	...	...	68.4	52.9	11.7	...	20.7	26.8	...	...	...	...	...	...	...	...	...	...	3.6
3.8	...	...	51.2	3.3	...	...	...	...	...	...	...	65.1	51.8	13.5	10.9	26.3	32.4	...	...	...	...	...	...	...	...	...	...	3.8
4.0	...	...	55.1	0.0	...	...	...	...	...	...	...	62.0	50.7	15.3	16.6	32.4	36.6	...	...	...	...	...	...	...	...	...	...	4.0
4.2	...	...	60.0	...	3.0	...	...	...	...	...	...	59.1	49.7	17.5	23.9	36.2	40.3	...	...	...	...	...	...	...	...	...	...	4.2
4.4	...	...	66.4	...	6.7	...	...	...	...	...	...	56.4	48.6	19.7	33.5	39.3	43.1	...	...	...	...	...	...	...	...	...	...	4.4
4.6	...	...	74.9	...	11.1	...	...	...	...	...	...	53.7	47.5	21.9	44.9	41.3	45.7	94.3	...	...	...	...	...	...	...	...	...	4.6
4.8	...	...	85.6	...	16.5	...	...	...	...	...	...	51.2	46.4	24.1	56.6	43.5	48.3	91.5	...	...	...	...	...	...	...	...	...	4.8
5.0	...	...	100.0	...	22.6	...	99.2	...	...	...	...	49.0	45.4	26.3	67.8	45.7	51.5	87.8	94.3	...	...	...	...	...	...	...	...	5.0
5.2	...	...	...	...	28.8	87.1	98.4	...	...	...	...	46.9	44.3	28.6	76.8	48.4	53.6	83.6	91.5	3.2	...	...	...	...	...	...	...	5.2
5.4	...	...	...	...	34.4	78.0	97.3	...	...	...	...	44.7	43.2	31.0	84.0	51.3	58.2	77.6	87.8	5.0	...	...	...	...	...	...	...	5.4
5.6	...	...	...	...	39.1	70.3	95.5	...	...	...	...	42.4	42.0	33.4	89.3	55.0	63.6	71.8	83.1	7.3	94.3	...	...	...	...	...	...	5.6
5.8	...	...	...	...	42.4	64.5	92.8	...	...	...	...	40.0	40.8	35.8	...	58.8	68.7	66.5	77.6	9.7	91.7	...	...	...	...	...	...	5.8
6.0	...	...	...	...	45.0	60.3	88.9	...	...	...	...	37.4	39.7	38.3	...	63.9	73.6	61.8	71.7	12.4	88.0	...	...	...	...	...	...	6.0
6.2	...	...	...	...	46.7	57.2	83.0	...	...	...	...	34.5	38.4	40.8	...	69.5	78.5	58.2	66.4	15.2	83.3	43.4	...	...	...	...	...	6.2
6.4	...	...	...	...	...	54.8	75.4	...	...	...	...	31.4	37.0	43.3	...	74.1	83.3	55.5	61.7	17.9	77.9	40.4	...	...	...	...	...	6.4
6.6	...	...	...	...	...	53.2	65.3	...	...	...	...	27.9	35.6	45.8	...	83.5	87.4	...	58.0	20.8	72.0	36.5	...	...	...	...	...	6.6
6.8	...	...	...	...	...	...	53.4	...	...	...	...	23.5	34.2	48.3	...	87.4	91.0	...	55.3	22.2	66.6	31.4	...	...	...	...	...	6.8
7.0	...	...	...	...	...	...	41.3	53.3	...	...	...	19.0	32.9	50.9	...	90.0	93.2	...	...	23.7	61.9	25.4	86.2	86.4	...	...	...	7.0
7.2	...	...	...	...	...	...	29.6	55.0	...	...	...	13.8	31.7	53.4	...	91.8	94.9	...	...	25.2	58.1	19.6	79.6	80.6	44.7	...	...	7.2
7.4	...	...	...	...	...	...	19.7	57.6	...	...	...	9.8	30.6	55.8	...	93.0	95.8	...	...	26.7	55.3	14.6	71.3	72.8	42.0	...	...	7.4
7.6	...	...	...	...	...	...	12.8	60.8	...	...	...	6.8	29.6	58.2	...	93.8	96.8	...	...	28.6	...	10.2	62.0	63.2	39.3	...	...	7.6
7.8	...	...	...	...	...	...	7.4	65.2	53.0	...	...	4.6	28.8	60.5	...	...	...	...	...	31.2	...	6.6	52.0	52.1	33.7	43.9	...	7.8
8.0	...	...	...	...	...	...	3.7	70.6	55.4	...	...	...	28.1	62.8	...	...	...	...	...	33.9	...	...	42.0	41.1	27.9	41.6	...	8.0
8.2	...	...	...	...	...	...	...	75.9	58.0	...	...	...	27.6	65.0	...	...	...	...	46.4	36.9	...	...	31.9	31.4	22.9	38.4	...	8.2
8.4	...	...	...	...	...	...	...	81.2	62.1	...	...	...	27.0	67.2	...	...	...	...	43.9	39.9	...	...	22.5	23.0	17.3	34.8	...	8.4
8.6	...	...	...	...	...	...	...	86.2	66.9	94.7	...	...	26.3	69.3	...	...	...	...	40.9	42.7	45.4	...	16.0	15.9	13.0	30.7	...	8.6
8.8	...	...	...	...	...	...	...	90.1	73.6	92.0	...	...	25.2	71.3	...	...	...	45.5	36.8	...	42.8	...	11.7	10.3	8.8	23.3	...	8.8
9.0	...	...	...	...	...	...	...	93.2	83.5	88.4	...	...	24.0	73.2	...	...	...	43.2	31.8	...	39.2	...	...	...	5.3	17.7	...	9.0
9.2	...	...	...	...	...	...	...	...	95.6	84.0	...	...	22.6	75.1	...	...	...	40.0	26.2	...	34.7	...	...	...	...	13.3	10.0	9.2
9.4	...	...	...	...	...	...	...	...	...	78.9	87.0	...	21.4	77.0	...	...	...	35.8	20.4	...	29.3	...	...	...	...	9.2	18.4	9.4
9.6	...	...	...	...	...	...	...	...	...	73.2	75.5	...	20.2	78.8	...	...	...	30.8	15.2	...	23.6	...	...	...	...	5.2	29.3	9.6
9.8	...	...	...	...	...	...	...	...	...	67.2	65.1	...	19.0	80.4	...	...	...	25.0	10.8	...	19.0	...	...	...	...	4.1	42.0	9.8
10.0	...	...	...	...	...	...	...	...	...	62.5	59.6	...	18.1	81.8	...	...	...	19.4	7.4	...	13.1	...	...	...	...	2.3	53.4	10.0
10.2	...	...	...	...	...	...	...	...	...	58.8	56.4	...	17.1	83.1	...	...	...	14.3	...	...	9.2	...	...	...	...	...	63.7	10.2
10.4	...	...	...	...	...	...	...	...	...	55.7	54.1	...	16.5	84.3	...	...	...	10.0	...	...	6.2	...	...	...	...	...	73.1	10.4
10.6	...	...	...	...	...	...	...	...	...	53.6	52.3	...	16.0	85.4	...	...	...	6.9	...	...	...	...	...	...	...	...	81.2	10.6
10.8	...	...	...	...	...	...	...	...	...	52.2	...	...	15.5	86.5	...	...	...	...	...	...	...	...	...	...	...	...	87.9	10.8
11.0	...	...	...	...	...	...	...	...	...	51.2	...	...	14.7	87.8	...	...	...	...	...	...	...	...	...	...	...	...	...	11.0
11.2	...	...	...	...	...	...	...	...	...	50.4	...	...	13.5	89.3	...	...	...	...	...	...	...	...	...	...	...	...	...	11.2
11.4	...	...	...	...	...	...	...	...	...	49.5	...	...	11.7	91.3	...	...	...	...	...	...	...	...	...	...	...	...	...	11.4
11.6	...	...	...	...	...	...	...	...	...	48.7	...	...	9.1	94.5	...	...	...	...	...	...	...	...	...	...	...	...	...	11.6
11.8	...	...	...	...	...	...	...	...	...	47.6	...	...	5.5	99.0	...	...	...	...	...	...	...	...	...	...	...	...	...	11.8
12.0	...	...	...	...	...	...	...	...	...	46.0	...	...	1.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12.0
12.2	...	...	...	...	...	...	...	...	...	43.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12.2
12.4	...	...	...	...	...	...	...	...	...	39.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12.4
12.6	...	...	...	...	...	...	...	...	...	31.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12.6
12.8	...	...	...	...	...	...	...	...	...	21.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12.8

Indicator	Acid side	pH range	Alkaline side
Cresol red, 1st range	red	0.2– 1.8	yellow
m-Cresol purple, 1st range	red	1.2– 2.8	yellow
Thymol blue, 1st range	red	1.2– 2.8	yellow
Metanil yellow	red	1.2– 2.3	yellow
Tropaeolin 00 (orange IV)	red	1.4– 3.2	yellow
2,6-Dinitrophenol	colourless	1.7– 4.4	yellow
Benzyl orange	red	1.9– 3.3	yellow
2,4-Dinitrophenol	colourless	2.0– 4.7	yellow
p-Dimethylaminoazobenzene	red	2.9– 4.0	yellow
Bromophenol blue	yellow	3.0– 4.6	violet
Congo red	blue	3.0– 5.0	red
Bromochlorophenol blue	yellow	3.0– 4.6	purple
Methyl orange	red	3.1– 4.4	yellow
Bromocresol green	yellow	3.8– 5.4	blue
2,5-Dinitrophenol	colourless	4.0– 5.8	yellow
Methyl red	red	4.2– 6.3	yellow
Azolitmin (litmus)	red	4.4– 6.6	blue
Propyl red	red	4.6– 6.6	yellow
p-Nitrophenol	colourless	4.7– 7.9	yellow
Bromocresol purple	yellow	4.8– 6.8	purple
Bromophenol red	yellow	4.8– 6.8	purple
Chlorophenol red	yellow	5.0– 6.9	purple
Bromothymol blue	yellow	6.0– 7.6	blue
m-Nitrophenol	colourless	6.6– 8.6	yellow
Neutral red	red	6.8– 8.0	yellow
Phenol red	yellow	6.8– 8.4	red
Rosolic acid	brown	6.9– 8.0	red
Cresol red, 2nd range	yellow	7.2– 8.8	purple
α-Naphtholphthalein	brown	7.3– 8.7	green
Orange I (Tropaeolin 000 No. 1)	yellow	7.6– 8.9	rose
m-Cresol purple, 2nd range	yellow	7.6– 9.2	purple
Thymol blue, 2nd range	yellow	8.0– 9.6	blue
o-Cresolphthalein	colourless	8.2– 9.8	red
Phenolphthalein	colourless	8.3–10.0	red
Thymolphthalein	colourless	9.3–10.5	blue
β-Naphthol violet	yellow	10.0–12.0	violet
Alizarin yellow R	yellow	10.0–12.1	brown
Alizarin yellow GG	yellow	10.0–12.0	orange
Nitramine	colourless	10.8–13.0	brown
Poirrier blue	blue	11.0–13.0	red
Tropaeolin 0 (resorcin yellow)	yellow	11.1–12.7	orange

Many of the spectral emission lines listed in the tables below are readily detectable only in the hotter flames such as oxy-hydrogen or oxy-acetylene and in some cases only in the inner cone.

For further data on flame photometry see the literature[1].

References

[1] MAVRODINEANU and BOITEUX, *L'analyse spectrale quantitative par la fl*... Masson, Paris, 1954; DEAN, J.A., *Flame Photometry*, McGraw-Hill, ... York, 1960; MACINTYRE, I., *Advanc.clin.Chem.*, 4, 1 (1961).

[2] From MACINTYRE, I., in LONG, C. (Ed.), *Biochemists' Handbook*, Spon, ... don, 1961, page 10. Reproduced by kind permission of the author and ... lishers.

Flame lines and bands of analytical importance[2]

The emissions are arranged in order of wave length. Inclusion does not necessarily mean that the emission is suitable for quantitative measurement of the element concerned. Band emissions are given at the most sensitive wave length and are marked '*b*'.

Wave length (nm)	Element	Wave length (nm)	Element	Wave length (nm)	Element
228.8	Cd	375.8	Fe	495 *b*	B
253.7	Hg	377.6	Tl	497 *b*	Ti
285.2	Mg	378.6	Ru	500 *b*	Zn
303.4	Sn	383 *b*	Mg	510 *b*	Be
307.6	Zn	385.6	Fe	518 *b*	Ti
317.5	Sn	386.0	Fe	520.5	Cr
324.8	Cu	387.3	Co	520.6	Cr
326.1	Cd	387.4	Co	520.8	Cr
327.4	Cu	396.2	Al	521 *b*	B
328.1	Ag	403.3	Ga	535.0	Tl
330.2	Na	403.5	Mn	540 *b*	Mo
330.3	Na	404.4	K	548 *b*	B
338.3	Ag	404.7	K	550 *b*	U
340.5	Pd	405.8	Pb	552 *b*	Dy
341.2	Co	407.8	Sr	553.6	Ba
341.5	Ni	410.2	In	554 *b*	Ca
343.5	Rh	417.2	Ga	560 *b*	La
344.6	K	420.2	Rb	562 *b*	Pr
344.7	K	421.6	Sr	565 *b*	Tb
349 *b*	Sn	422.7	Ca	570 *b*	Gd
350.2	Co	425.4	Cr	570 *b*	Dy
350.3	Rh	427.5	Cr	571 *b*	Pr
351.5	Ni	429.0	Cr	576 *b*	V
352.4	Ni	430.4	Nd	589.0	Na
352.5	Ni	438 *b*	La	589.5	Na
353.0	Co	442 *b*	La	600 *b*	Mo
360.5	Cr	444 *b*	Y	600 *b*	Tb
361.0	Pd	450 *b*	Nb	622 *b*	Ca
363.5	Pd	450 *b*	Gd	653 *b*	Sm
364 *b*	Te	451.1	In	660 *b*	Nd
368.4	Pb	455.4	Ba	670.8	Li
369.2	Rh	455.5	Cs	681 *b*	Sr
371 *b*	Mg	460.7	Sr	715 *b*	Ti
372 *b*	Te	460.9	Sc	766.5	K
372.0	Fe	462 *b*	Gd	769.9	K
372.3	Fe	462 *b*	Nb	780.0	Rb
372.8	Ru	466.2	Eu	794.8	Rb
373.3	Fe	467 *b*	Al	818.3	Na
373.5	Fe	471 *b*	Be	819.5	Na
373.7	Fe	472.3	Bi	852.1	Cs
374.3	Fe	481 *b*	Ce	873 *b*	Ba
374.6	Fe	483 *b*	Y	894.3	Cs
374.8	Fe	484 *b*	Al		
374.9	Fe	493.4	Ba		

Detailed flame spectra of sodium, potassium, calcium and magnesium[2]

The ionization potential of the neutral atom and excitation potential of singly ionized atom (expressed in eV) are given in brackets. '*r*' represe... transition to ground state. The most suitable wave lengths for analysis ... given in *italics*. 'I' signifies the neutral atom, 'II' the singly ionized atom.

Element	Wave length (nm)	Emitter	Excitation potential (eV)
Na (5.14; 33.3)	285.3 *r*	I	4.06
	330.2 *r*	I	3.75
	330.3 *r*	I	3.75
	568.3	I	4.03
	568.8	I	4.03
	589.0 *r*	I	2.10
	589.5 *r*	I	2.10
	818.3	I	3.61
	819.5	I	3.61
K (4.34; 20.6)	344.6 *r*	I	3.59
	344.7 *r*	I	3.59
	404.4 *r*	I	3.06
	404.7 *r*	I	3.06
	693.9	I	3.40
	696.4	I	3.40
	766.5 *r*	I	1.61
	769.9 *r*	I	1.61
Ca (6.11; 3.12)	*422.7* *r*	I	2.93
	393.4 *r*	II	3.15
	396.8 *r*	II	3.12
	622	CaO	1.97
	554	CaO	
Mg (7.64; 4.42)	277.7	I	7.17
	277.8	I	7.17
	278.0	I	7.17
	278.1	I	7.17
	278.3	I	7.17
	285.2 *r*	I	4.34
	333.0	I	6.43
	333.2	I	6.43
	333.7	I	6.43
	382.9	I	5.85
	383.2	I	5.85
	383.8	I	5.85
	279.6 *r*	II	4.43
	280.3 *r*	II	4.42
	371	MgO	3.49
	383	MgO	3.38

(For references see page 291)

capes from the atom, giving rise to a slow, positively charged ion and a very fast secondary electron. If the ions and electrons are not immediately separated by means of an electric field they recombine and remain undetected. Electrons slowed by multiple collisions can be captured by reactive gas molecules and give rise to negative ions. Furthermore, an ion strongly accelerated in an electric field may collide with a neutral gas molecule and thereby give rise to a fresh positive ion and electron (see GEIGER counters, below). X and γ-rays must also first give rise to free electrons before they can be detected, and since the probability of ionization occurring decreases rapidly with increasing quantum energy, the harder such radiation is, the more difficult it is to detect.

Ionization chambers. While ionization chamber measurements form the absolute basis of dosimetry (see below), the method is too slow and insensitive for detecting short-lived radioactivity in the μCi range and lower.

Geiger counters. These are gas-filled counters operating at reduced pressure. They do not measure continuous currents like ionization chambers but register collision ionizations. The primary ions in the counter gas are multiplied by applying an electric field of 800–2000 V (ion 'avalanche'). In the range of roughly 200–600 V the number of ions present is strictly proportional to the number of primary ions (proportional region), and for this reason proportional counters can be used to distinguish β-rays from highly ionizing particles. At higher voltages (> 800 V) a 'plateau' region is reached in which the ion avalanche is largely independent of the intensity of primary ionization. The life-time of a gas-filled counter is limited by the capacity of the gas to a total of 10^9–10^{10} collision discharges; for halogen-filled tubes it is about 10^{12}. During a collision ionization, which lasts about 0.1 ms, the counter is refractory to additional ionizations (counter dead time). In the plateau region the resolving time – or minimum time between two counted discharges – is about 0.2 ms, in the proportional region about 1 μs.

Semiconductor detectors. When silicon or germanium crystals are irradiated, ionization occurs and secondary electrons are released. With the aid of electron donors (for example lithium) these can be conducted to electrodes and measured as current pulses. Such drift detectors are suitable for detecting corpuscular and low-energy X and γ-rays at room temperature. On account of their extremely small size they can even be implanted.

Scintillation

This is the name given to the light flashes emitted by luminescent substances when excited by high-energy radiation. The flashes can in turn liberate photoelectrons from photosensitive substances (for instance caesium/antimony phosphors); the photoelectrons are amplified 10^7–10^8 times by means of a phototube multiplier before being converted into current pulses. The pulse height depends on the energy of the original γ- or corpuscular radiation, and the pulses can thus be sorted by means of a discriminator (pulse height analyser). By using different discriminator channels the different nuclides in a mixture of isotopes can be determined either successively or simultaneously.

Solid scintillators. The commonest type in use in nuclear medicine consists of single crystals of thallium-activated sodium iodide. Since the decay time of the fluorescence is only 0.25 μs the scintillation crystals have a resolving power about a thousand times greater than gas-filled counters. Moreover, the pulse yield for X and γ-rays is 10–1000 times greater – depending on the crystal volume and surface – as a result of the higher density of the material. Since there is no dissipation of the crystals the life-time of these scintillation detectors is limited only by that of the replaceable multiplier and its semi-permanent photosensitive layer. The wave length of the luminescent radiation is about 410 nm. Organic scintillators and plastic scintillators have a decay time of 5–24 ns, their secondary luminescence a wave length of 410–440 nm.

Liquid scintillators. The radiation from preparations emitting β-rays, soft X rays or γ-rays can be measured with particularly high pulse yield if they are mixed directly with a scintillator solution.

Only a few highly purified alkylbenzenes (mainly toluene and xylene) and ethers (anisole, veratrole, dioxan) are suitable as *solvents*. They transmit the radiation energy to the scintillators by ionization via metastable (10^{-12}–10^{-9} s) excited states. This type of energy transmission is subject to interference by fluorescence quenching.

The *'first' scintillator* usually consists of a solution of 2,5-diphenyloxazole (PPO) in toluene (4 g/l). Its fluorescence, which is highly subject to quenching, has a maximum at 380 nm. Since the photocathodes of many multipliers develop optimum activity only at wave lengths above 400 nm the spectrum of the primary fluorescence must be displaced to higher wave lengths by using a second fluorescent substance. Other suitable first scintillators are 2-[...] 5-(4-diphenyl)-1,3,4-oxadiazole (PBD or PBO) (in toluene, 360 nm) and *p*-terphenyl (8 g/l; 350 nm). 2,5-Bis-(2-[5-*tert.* [...] benzoxazolyl])thiophen (BBOT) emits light at 435 nm and [...] fore needs no second scintillator.

The *'second' scintillator* converts the ultraviolet radiation fr[...] first by fluorescence into radiation with a wave length of [...] 420 nm. It usually consists of 1,4-di-(2-[5-phenyloxazolyl])b[...] (POPOP) in toluene at a concentration of 0.1–2.0 g/l. A sm[...] of the fluorescence of this substance is due to primary radio[...] and reduces quenching in the first scintillator.

If the radioactive preparation in question is insoluble in t[...] vent, other substances must be added to make it soluble. Like[...] however, these substances considerably reduce the pulse yi[...] fluorescence quenching. Since the latter also causes spectr[...] placement, however, it can be detected and corrected by discri[...] tory measurements in two channels or by comparison with in[...] or external standard radiators.

Autoradiography

The oldest method of detecting radioactivity is the photogr[...] one. Both electromagnetic and corpuscular radiation cause elec[...] to be expelled from the halogen atoms in the silver halide grai[...] a gelatin emulsion. Each electron reduces a silver ion (Ag[...] metallic silver. The sites at which this occurs in the silver h[...] grains constitute 'development centres' where the developer b[...] the reduction of the whole grain to black metallic silver. [...] resulting degree of intensification is about 10^{12}.

Macroscopic autoradiography is used in nuclear medicine m[...] for radiation exposure monitors (film badges); another use i[...] localization of radioactivity in chromatograms and in o[...] sections of large surface area. The film used is high-sensitivity X[...] film; for pure γ-ray sources an intensifying screen is usually ne[...] sary, though this reduces the sharpness of the image. Image in[...] sity is dependent on a great many factors, so that the exposure t[...] must be decided empirically in each case. As an example, an a[...] radiograph taken by a ^{131}I isotope with a radioactivity of 10 nCi/[...] requires an exposure time of 2–4 days.

Microscopic autoradiography of sections 5–10 μm thick requ[...] an activity concentration in the tissue of about 10 μCi/ml (assum[...] uniform distribution) if satisfactory blackening of films is to [...] obtained in 2–16 days. In the case of weakly radioactive sour[...] self-exposure times longer than three times the half-life are po[...] less. The activity of weak β-emitters (^3H, ^{14}C, ^{35}S) can be de[...] mined semiquantitatively by counting the blackened grains.

Dosimetry of incorporated nuclides (see also pages 218–221)

If a β-emitter is uniformly distributed throughout an orga[...] the whole body, and if the range of its β-rays is small compared w[...] the volume of matter concerned, then the absorbed dose D_∞ [...] complete disintegration is given by

$$D_\infty = K_\beta \times \alpha_0 \times \frac{T_{\text{eff}}}{T_{1/2}} \text{ [rd]}$$

where α_0 is the initial activity concentration A_0/m (in μCi/g), T[...] the effective half-life (in days), $T_{1/2}$ the physical half-life (in days), [...] a characteristic constant for each β-emitter (see the table on pag[...] 292 and 293). K_β is given by

$$K_\beta = 73.9 \times \bar{E}_\beta \times T_{1/2} \text{ [rd g μCi}^{-1}]$$

where $T_{1/2}$ is in days and $\bar{E}_\beta$ is the mean energy in MeV of the [...] emission ($\approx 0.3\ E_{max}$; see the table on pages 292 and 293).

The hourly absorbed dose rate after the lapse of a time t from i[...] corporation is given by

$$\dot{D}_\beta = 0.0288 \times K_\beta \times \alpha_0 \times \frac{1}{T_{1/2}} \times e^{-0.693\frac{t}{T_{\text{eff}}}} \text{ [rd h}^{-1}]$$

where $T_{1/2}$ is in days, t and T_{eff} in any time unit provided it is th[...] same for both. For values of $t \ll T_{\text{eff}}$ the exponential factor can b[...] assumed to be unity.

The absorbed dose D_∞ for complete disintegration of a u[...] formly distributed γ-emitter is given by

$$D_\infty = K_\gamma \times \alpha_0 \times \frac{T_{\text{eff}}}{T_{1/2}} \times \varrho_0 \times g \text{ [rd]}$$

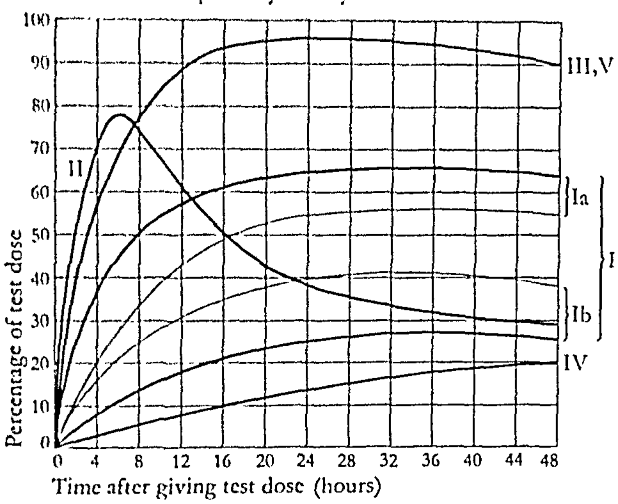
$$K_\gamma = 0.0338 \times \Gamma \times T_{1/2} \text{ [rd cm}^2 \text{ μCi}^{-1}]$$

(For references see page 291)

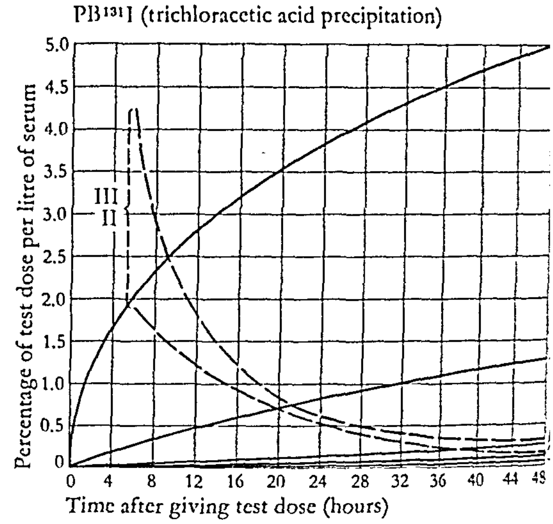
Typical radio-iodine test results

I Normal values
Ia Normal range in iodine-deficiency areas
Ib Normal range in iodine-surplus areas
II Rapid iodine turnover in the rebound effect, severe hyperthyroi hereditary myxoedema (curves occasionally seen are shown b lines)
III Hyperthyroidism (curves occasionally seen are shown by broken
IV Ingestion of drugs containing iodine, thyroid block, hypothyroi
V Iodine deficiency

Radio-iodine uptake by the thyroid



PB¹³¹I (trichloracetic acid precipitation)



where F is the fraction of ^{131}I-T_3 taken up by the cells and H the haematocrit value.

In order to be able to compare T_H values with older values in the literature converted to a normal haematocrit value of 40% (T_{40}), WECHSELBERGER et al.[6] have introduced another coefficient K': $T_{40} = T_H + K'$. K' is calculated from one of the following two formulae, depending on whether the pathological haematocrit is above or below 40%:

$$\text{For } H = 20\text{–}40\%,\ K' = +0.15\ (40 - H)$$

$$\text{For } H = 40\text{–}80\%,\ K' = -6.5 \times 10^{-3}\ (H^2 - 50\ H + 400)$$

K' values for various values of H are as follows:

H	K'	H	K'	H	K'
20%	+3.00	45%	−1.13	70%	−11.70
25%	+2.25	50%	−2.60	75%	−14.78
30%	+1.50	55%	−4.38	80%	−18.20
35%	+0.75	60%	−6.50		
40%	+0.00	65%	−8.93		

Variants of the T_3 test often use synthetic resins, dextran gels and other adsorbents in place of erythrocytes. Whatever form the test takes, however, the adsorption of free T_3 depends mainly on two variables: the concentration of T_4 or any other substance capable of displacing T_3, and the TBG, prealbumin and albumin concentrations. The concentration of T_3 in the plasma usually has practically no effect. When the various extrathyroidal factors affecting the results are allowed for, relative T_H values of over 16–17% point in all probability to hyperthyroidism, values below 10–12% to hypothyroidism. Normal values fluctuate slightly, depending on how often the erythrocytes are washed and other procedural differences.

During pregnancy the T_H value is greatly decreased, often also during menstruation. Pathological values are seen in some extrathyroidal diseases, particularly disturbances of the plasma proteins, some types of leukaemia, and uraemic, hepatic and diabetic coma. The following drugs also affect the T_H value: anabolic agents, androgens, anticoagulants, corticosteroids, diphenylhydantoin, Evans blue, furosemide, gestagens (ovulation inhibitors), oestrogens, phenothiazine, phenylbutazone and derivatives, salicylates, sulphobromophthalein, sulphonamides, thyroxine, tri-iodothyronine and thyrotropin, as well as many radionuclides given for diagnostic or therapeutic purposes.

'Free' thyroxine in blood[7]

The serum of euthyroidal persons contains about 50 ng o tein-bound iodine per millilitre, made up principally of thy (T_4). After addition of ^{131}I-T_4, only about 0.05% of the s activity is dialysable against aqueous buffer solution, the rem 99.95% being fairly firmly bound to protein. It follows that n serum contains about 0.025 ng of dialysable ('free') T_4 per mill In hyperthyroidism this is increased to about 0.13 ng/ml, in thyroidism decreased to about 0.004 ng/ml. Unlike the T_H v the serum T_4 level changes little in pregnancy. Its determinati subject to the errors common to all chemical methods of d mining protein-bound iodine.

Thyroxine metabolism[8]

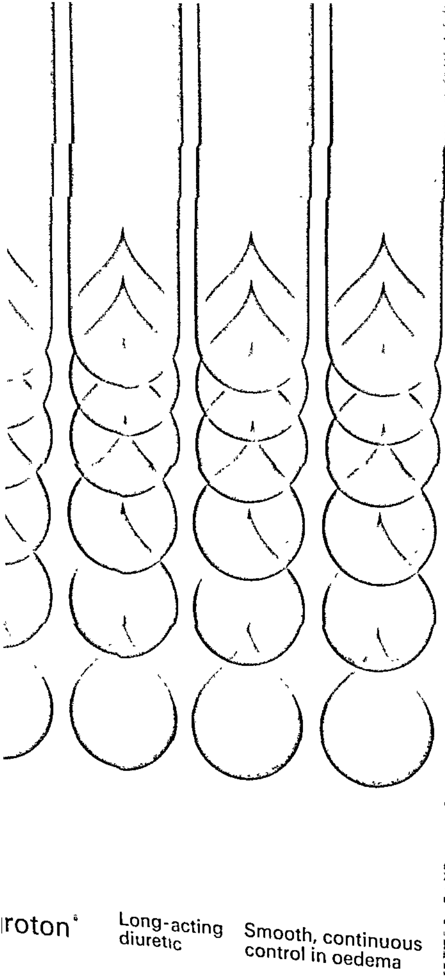
In healthy subjects the biological half-life of intravenous jected ^{131}I-T_4 after reaching diffusion equilibrium is about 7 days. The extrathyroidal reserve of T_4 has been estimated at 80 of which about 100 µg is broken down per day. In hyperthyro the *extra*thyroidal T_4 reserve is increased to about 1800 µg in of the augmented rate of breakdown (about 330 µg/day; hal about 4 days). In hypothyroidism the reserve is reduced to a 360 µg, and the rate of breakdown to about 30 µg/day, with half-life increased to about 8½ days. Determination of the in rapid rate of disappearance of ^{131}I-T_4 is also of value in differe diagnosis. In vivo studies of T_4 are subject to interference by turbances of liver function and by changes in the protein bind

Thyroid scintigraphy

Two methods of obtaining scintigrams of the thyroid are in rent use. In the older and more usual method a collimated scin tion crystal scans the thyroid in a horizontal plane. The impu picked up are recorded simultaneously on paper, in some ins ments in different colours showing the rate at which the impu are received. The other method (scintillation camera) uses eith very large, fixed scintillation crystal about 25 cm in diameter carrying some 20 photomultipliers, or a group of ten or more s tillation detectors which scan the object simultaneously. The pulses are usually stored for a period ranging from a few second minutes before being converted into a photographic image.

The principal radioactive sources used in thyroid scintigra are $^{131}I^-$ and $^{99}Tc^mO_4^-$. ^{131}I scintigraphy is usually combined the radio-iodine test, the scintigram being taken 12–48 hours a giving a test dose of 30 µCi $Na^{131}I$ (2–10 µCi in children).

Although the use of $^{99}Tc^m$ requires a tenfold larger dose, magnitude of the radiation load on the thyroid is about 100 t



ited by enteral loss of protein the
over 10%. Although ⁵¹Cr-human
olymer it is the indicator of choice
tant and medium half-life.

ıf¹³

d the gastrogenic 'intrinsic factor',
s absorbed from the diet and from
im, whence it is transported to the
84) Since the liver can store addi-
ng's test uses an oral dose of 0 1–0 5
) 1–0 5 μCi) given to the fasting pa-
uscular injection of 1000 μg cyano-
saturate the liver and serum pro-
', the kidneys now excrete over 5%
dministered If the renal excretion
peated a week later with the simul-
sic factor. If the renal excretion is
re is a deficiency of intrinsic factor,
ıy of the gastric mucosa and carci-
ll low the patient is suffering from

serve amounts to about 40 mg/kg
0 mg/kg body weight, so that the
4 g of iron The dose of 5–10 μCi
metabolic iron studies is therefore
ke of iron is about 17 mg, of which
d The daily iron turnover in the
f 7–15 g of transferrin and 2–5 mg
ıes more than the amount absorbed
urnover can be calculated from the
and the biological half-life (T_b) of
r 100 ml of whole blood in accor-
la

natocrit
0

ansferrin binding, ⁵⁹Fe passes into
120 minutes, and within 8–24 hours
he bone marrow Within 6–14 days
istered has reappeared in the blood
Extramedullary blood-forming
evealed by radioactivity measure-
pleen *Determination of the ferro-*
bservation time of 2–4 weeks

yte volume¹⁵ ¹⁶

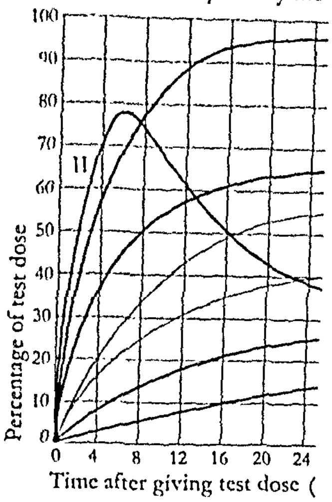
e rate of disappearance of tagged
0–95% of the chromium of which
f globin, the amount depending on
ı takes 10–25 days and requires a
normal adults the half-life of the
24–35 days) At the same time the
r and sacrum is determined by sur-
ıe uptake by the spleen must be
leen/liver activity ratio exceeds 1 2
measured at the same time as the
merely 1–3 activity measurements
s 10–20 minutes after intravenous
⁵¹Cr-tagged erythrocytes For nor-

rapidly and simply determined by
) μCi of tagged (¹³¹I, ¹²⁵I) human
or of 10–30 μCi of ⁵¹Cr-albumin
after the injection the rate at which
plasma is mainly dependent on the
tein with the normal protein in the
iis a gradual movement of activity
y extrapolating the activity curve
s the activity concentration at the
approximately calculated For nor-

Typical radio-iodine test results

I Normal values
Ia Normal range in iodine-deficiency
Ib Normal range in iodine-surplus are

Radio-iodine uptake by the



where F is the fraction of $^{131}I\text{-}T_3$
haematocrit value.

In order to be able to compare
literature converted to a normal
WECHSELBERGER et al.[6] have int
$T_{40} = T_H + K'$. K' is calculated fr
mulae, depending on whether the
or below 40%:

For $H = 20\text{–}40\%$, $K' = +0.15$

For $H = 40\text{–}80\%$, $K' = -6.5$

ns, particularly the 'toxic' variety, have a largely autonomous abolism independent of anterior pituitary control, suppression three days with daily doses of 50–100 μg of tri-iodothyronine

led inflammatory areas in a goitrous gland.
'or whole-body scintigraphy aimed at locating an aberrant goitre

y when there is no danger of compression.

dneys[9]

Radiography of the kidneys at present makes use principally of odohippuric acid (IHA). With ^{131}IHA the applied dose is about ; μCi/kg body weight, with ^{131}IHA usually 0.4 μCi/kg body ight. The nephrogram reveals two main phases, both of which n be evaluated.

(a) A rising phase commencing about 10–15 seconds after the ection and reaching a maximum in 4–6 minutes. This phase represents the uptake, storage and secretion of the IHA and can often be vided into a very steep part (initial phase) and rather less steep rt (functional phase) separated by a more or less sharp break.

il details are shown up better with ^{203}Hg- or ^{197}Hg-chlormerodrin intigraphy than with IHA

iver[10]

Intravenous injection of 10–30 μCi ^{131}I Bengal red is followed

inutes the activity is concentrated in the gallbladder region. The ise and fall in the activity are determined by the blood flow and unctional capacity of the liver. Scintigraphy of the liver can also e carried out with colloidal radiogold (^{198}Au, 40–100 μCi i.v.), which is phagocytosed by the cells of the reticuloendothelial system but this isotope gives no picture of the gallbladder

Brain[11]

Suitable isotopes for the d

counting, ^{68}Ga requires an ANGER positron camera

Gastroenterology

Enteral excretion of plasma proteins or polyvinylpyrrolidone (PVP)[12]

In 4 days, normal persons excrete 0.3–1.0% of a tracer dose o 5–10 μCi ^{131}I-PVP or 20–30 μCi ^{51}Cr-albumin in the faeces. Afte 6 days the upper limit of the total activity excreted is about 1.5% o

Radioimmunological methods[17]

Insulin antibodies

Humoral antibodies in the γ-globulin range that reversibly adsorb insulin instead of precipitating it appear in the blood of only those persons who have previously been given this drug – usually during the 3–6 weeks after the first insulin injection. The binding capacity of these antibodies can be determined by electrophoretic, chromatographic or adsorption-equilibrium methods using insulin tagged with radio-iodine. Binding capacities of over 0.8–1.0 mg of ^{131}I-insulin per litre serum (≈ 20–25 IU/l serum) are often, but not always, associated with intractable diabetes, very high values with insulin resistance. These antibodies are active not only against the homologous (sensitizing) insulin but also against insulin from other species. Thus anti-beef insulin human γ-globulin – formed in man when beef insulin is injected – binds not only the latter but also human and hog insulins. All quantitative immunological methods of determining the concentration of the hormone depend both on this nonspecificity and on the reversibility of the antigen-antibody binding.

Determination of hormone levels

Nonprecipitating antibodies to insulin and other hormone antigens are usually obtained from guinea-pigs. These antibodies bind the corresponding tagged hormones reversibly, for addition of nonradioactive hormone antigen causes the tagged hormone to be displaced from its binding with the species-nonspecific antibody. The higher the concentration of hormone, the less therefore is the amount of antigen activity carried by the antibody γ-globulins. The γ-globulin–hormone complexes can be separated from the unbound ('free') hormone by electrophoresis, chromatography, the adsorption-equilibrium method, immunoprecipitation or other selective precipitation techniques. Hormones that are adequately homogeneous and particularly suitable for determination by radioimmunological methods are insulin, glucagon, ACTH and growth hormone. The lower limit of determination lies in the nanogramme to picogramme range and is dependent on the specific activity of the tagged hormone antigens (5–50 mCi of radio-iodine per milligramme of hormone) and on the hormone-binding capacity of the antibody γ-globulins.

Therapeutic uses[1]

In contrast to the natural radioactive isotopes, which on account of their gaseous decay products can only be used for therapeutic purposes when enclosed in a gastight container (needles, tubes or plaques of platinum, gold or monel metal), the artificial isotopes can mostly be used without enclosure and in either the solid or liquid form. The placing of the radioisotope in a circumscribed focus of disease with maximum possible protection of the surrounding healthy tissue can be achieved by various methods.

Teletherapy (γ-emitters)

Isotope ^{60}Co. Sources with a specific activity of 20–100 Ci/g are used, usually as cylinders 10 × 10 mm up to 25 × 25 mm. The source as purchased is fully shielded in a tungsten or lead container, the emergent radiation being controlled by an adjustable or exchangeable tungsten diaphragm. Exposure time is adjusted by a remote-

[illegible]

therapy. Crossfire technique, rotation therapy or arc therapy. Advantages over 200 kV X-ray therapy are: higher relative depth dose; sharper lateral limitation of the field; absorption in bone practically the same as in soft tissues (less injury to the bones); maximum dose 4–5 mm *beneath* the skin (dose on skin surface 25–30% of maximum, with correspondingly milder skin reaction). The biological effectiveness of the radiation from ^{60}Co is about 80% of that of 200 kV X rays, so that the dosages given are usually somewhat higher.

Isotope ^{137}Cs. Sources may be contaminated with the shorter-lived isotope ^{134}Cs (half-life 2.3 y compared with 30 y for ^{137}Cs), in which case there is a more rapid loss of activity. The advantage of this isotope lies in its longer half-life than ^{60}Co; its disadvantages are its much lower specific activity, necessitating larger sources and therefore larger penumbra, and its lower γ-energy, resulting in more injury to the skin and bones.

Contact therapy (β- and γ-emitters)

Pure β-*emitters* are used for the irradiation of surface foci (tion in dermatology and ophthalmology and are applied dir the lesion in suitable forms.

Isotopes ^{32}P *and* ^{90}Sr/^{90}Y. Maximum depth of penetration 5 effective range ca. 3 mm. Commercially available in the f flexible plastic foils containing 20% red phosphorus whic been activated in a reactor.

The Sr/Y mixture is available in metal capsules with a sil filter over the exit surface. Activity is due to the β-radiation daughter isotope ^{90}Y. Ophthalmological applicators shaped the corneal curvature are available.

A greater depth effect is obtained with γ-*emitters* applied surface to be treated. Commercially available is ^{60}Co granul soft plastic mass (Plastobalt) or as plastic spheres enclosed in gold foil. These provide optimal adaptation to surfaces of co shape. The dose of γ-emitters decreases sharply with incr depth since the intensity is inversely proportional to the squ the distance. ^{182}Ta is available in the form of wire in a plasti and is particularly suitable for ring sources for epibulbar irradi

Interstitial irradiation

Needles of solid γ-emitters. ^{60}Co is supplied as wire of the d alloy 'Cobanic' (55% nickel + 45% cobalt) in steel needles or tubes. These 'threads' are sewn into the lesion and have m advantages over rigid carriers.

^{182}Ta wire (0.4 mm diameter with platinum envelope 0.1 thick) is formed into hairpin-shaped loops which are insertec tumour tissue, particularly in the wall of the bladder.

^{192}Ir is also very suitable for interstitial application in this The threads are withdrawn from the tissues at the end of the diation period.

For tumours accessible for only a short time, 'seeds' of radio (^{198}Au) ca. 2.5 mm long and 0.8 mm in diameter are used, the diation being filtered out by means of an inactive gold or plati coating. Such seeds can be quickly and accurately placed ir tissue with the aid of a 'pistol' for which filled 'magazines' available. The magazines must be sterilized before placing ir pistol. Another equipment allows pieces of any desired length cut under shielding from radiogold wire coated with inactive g The pieces are then inserted into the tissue through a special Radiogold seeds have important advantages over radon seeds.

Needles of solid β-emitters. ^{90}Y (pure β-emitter) in the form ceramic bodies (1 mm Y_2O_3 spheres) is particularly suitable irradiation of the pituitary, either via the nose or by stereot Uniform distribution of the dose over the pituitary can be achie by implanting about 40 spheres. The total dose required for ra hypophysectomy is about 10 mCi.

Infiltration methods (β-emitters). The radioactive substance is jected directly into the tumour tissue in the form of a stabili colloidal solution. The irradiation can be assumed to be practic homogeneous when the individual depots are not more than 3 apart. Isotopes used: colloidal radiogold (^{198}Au), colloidal ^{32}P $Cr^{32}PO_4$, colloidal ^{90}Y. There is some loss of activity via the lym ducts with concentration in the neighbouring lymph glands.

For dosage calculation see pages 286 and 287.

Intracavitary irradiation

(*a*) Colloidal suspensions of radiogold (^{198}Au) are used for int peritoneal and intrapleural infusion in superficial or dissemina carcinomatosis. Individual doses of 100–150 mCi are given, repe ed if necessary after several months up to a total dose of 500 m The main activity is due to the β-radiation, with a small depth eff up to ca. 3 mm. This technique has recently been used for irradiati of the inner wall of the bladder, using 300 mCi of radiogold fo 4-hour period. The dosage can be obtained from a nomogram

(*b*) Solid applicators in the form of plastic masses contain ^{60}Co grains of diameter ca. 1 mm are used principally for irradiati of tumours of the mouth, nose and pharyngeal cavities. Beads ^{60}Co of diameter 6 mm are strung together for insertion into t oesophagus, or can be packed into natural or surgically opened bo cavities.

(*c*) Gynaecology: Sealed radium carriers (platinum filter capsule total content 50–130 mg of ^{226}Ra) introduced into the vagina, cerv and/or uterus.

Enteral and intravenous applications

A therapeutic effect from intravenous or peroral administrati of isotopes is only obtainable when the isotope can be concentr

Characteristics of radioactive nuclides with medical applications[1]

Nuclide	Half-life	Mode of decay	β-Radiation E_{max}	β-Radiation $\bar{E}_\beta$	E_β^{tot}	γ-Radiation[2] (energies in MeV)	Dose constants K_β $\left[\frac{\text{rd g}}{\mu\text{Ci}}\right]$	Dose constants Γ $\left[\frac{\text{R cm}^2}{\text{h mCi}}\right]$	Dose constants K_γ[3] $\left[\frac{\text{rd cm}^2}{\mu\text{Ci}}\right]$	β-range in water[3] (mm)	Reciprocal specific activity[4] $\left[\frac{\text{pg}}{\mu\text{Ci}}\right]$
1	2	3	4	5	6	7	8	9	10	11	12
^{3}H	12.36 y	β^-	0.018 (100)	0.005_5	0.005_5	–	1835	–	–	0.007	103
^{14}C	5568 y	β^-	0.156 (100)	0.049_6	0.049_6	–	7450×10^3	–	–	0.24	218×10^3
^{22}Na	2.58 y	β^+, EC, γ	+0.54 (89)	0.188	0.188	1.28 (100); 0.51 (178)	13100	11.7	3.72×10^2	2.1	160
^{24}Na	15 h	β^-, γ	1.39 (100)	0.550	0.550	2.75 (100); 1.37 (100)	25.6	18.1	0.39	6.4	0.113
^{32}P	14.4 d	β^-	1.71 (100)	0.695	0.695	–	739	–	–	8.0	3.52
^{35}S	87.5 d	β^-	0.167 (100)	0.049	0.049	–	316	–	–	0.3	23.4
^{36}Cl	2.85×10^5 y	β^-, EC	0.71 (98)	0.247	0.247	–	1900×10^6	–	–	2.7	30.5×10^6
^{42}K	12.47 h	β^-, γ	3.55 (82); 1.98 (18)	1.469	1.469	1.53 (18)	56.3	1.35	0.024	19	0.167
^{45}Ca	159 d	β^-	0.258 (100)	0.078	0.078	–	915	–	–	0.6	56.6
^{47}Ca	4.7 d	β^-, γ	2.00 (18); 0.69 (82)			1.30 (76); 0.81 (6); 0.50 (6)		5.1	0.81	9.6	1.69
^{51}Cr	27.8 d	EC, γ	–	–	0.0049	0.32 (9)	10	0.18	0.17	–	10.9
^{52}Mn	5.67 d	β^+, EC, γ	+0.58 (34)	0.084_5	0.088	1.46 (100); 0.94 (100); 0.73 (100); 0.51 (68)	36.9	18.5	3.6	2.2	2.27
^{54}Mn	297 d	EC, γ	–	–	0.0054	0.84 (100)	118.7	4.7	47	–	122.6
^{55}Fe	2.77 y	EC	–	–	0.0059	–	441	–	–	–	414
^{57}Co	267 d	EC, γ	–	–		0.136 (9); 0.122 (89); 0.0144 (6)		0.61	5.5	–	118
^{58}Co	71 d	β^+, EC, γ	+0.49 (15)			1.6 (5); 0.81 (99.5); 0.51		5.585	13.4	1.5	31.6
^{59}Fe	45 d	β^-, γ	*1.56 (0.3); 0.462 (54); 0.271 (46)*	0.128	0.128	1.29 (43); 1.10 (57); 0.19 (3)	432	6.2	9.4	1.5	20.6
^{60}Co	5.23 y	β^-, γ	1.48 (0.2); 0.312 (99.8)	0.095	0.095	1.33 (100); 1.17 (100)	1340	12.9	8.32×10^2	0.8	884
^{64}Cu	12.8 h	β^-, β^+, EC, γ	0.57 (39); +0.65 (19)	0.126	0.130	1.35 (0.5); 0.51 (38)	5.1	1.15	0.021	2.6	0.226
^{65}Zn	245 d	β^+, EC, γ	+0.324 (1.5)	0.002	0.010	1.12 (46); 0.51 (3)	181	2.8	23	1.2	122
^{71}As	18 d	β^-, β^+, EC, γ	1.36 (17.7); 0.72 (14.5); +1.5 (3.6); +0.91 (26.1)			0.635 (14.5); 0.596 (61); 0.51		4.4	2.6	7.0	9.93
^{75}Se	120 d	EC, γ	–	–		0.405 (15); 0.308 (1); 0.281 (28); 0.269 (54); 0.20 (2); 0.136 (40); 0.122 (12); 0.097 (2); 0.066 (7) and other weak lines		1.5	6.1	–	69
^{76}As	26.45 h	β^-, γ	2.97 (50); 2.41 (31); 1.76 (16); 0.36 (3)	1.078	1.078	2.06 (2); 1.41 (1); 1.21 (12); 0.65 (5); 0.56 (38)	87.8	2.4	0.089	15.7	0.642
^{82}Br	35.7 h	β^-, γ	0.45 (100)	0.134	0.134	1.48 (17); 1.32 (28); 1.04 (27); 0.83 (27); 0.78 (83); 0.70 (27); 0.62 (44); 0.55 (73)	14.7	14.5	0.73	1.6	0.942
^{85}Kr	10.6 y	β^-, γ	0.672 (<99.3); 0.15 (>0.7)			0.514 (~0.7)		0.02	2.6	2.5	2520
^{86}Rb	18.66 d	β^-, γ	1.78 (84); 0.71 (15); 0.23 (1)	0.627	0.627	1.08 (9)	864	0.51	0.32	8.7	12.3
^{89}Sr	51.5 d	β^-	1.46 (100)	0.555	0.555	–	2260	–	–	6.8	34.7
^{90}Sr	28.0 y	β^-	0.54 (100)	0.174	0.174 (0.20)	–	(1510×10^3)	–	–	2.2	7050
^{90}Y	64.5 h	β^-	2.26 (100)	0.917	0.917	–	182	–	–	11	1.86
^{99}Mo	67 h	β^-, γ	1.23 (85); 0.87 (~1); 0.45 (14)			0.780 (4); 0.741 (10); 0.181 (2); 0.041 (1)		0.73	0.17	[illegible]	[illegible]

¹¹³Sn	119 d	EC, γ	–	–	[illegible]	[illegible]					
¹²¹Te	17 d	EC, γ	–	–	0.009	0.57 (87) 0.51 (13); 0.07 (2)	6.3	4.4	2.5	–	15.7
¹²⁴Sb	60.5 d	β^-, γ	0.97 (9), 0.61 (49), 0.24 (14)	0.371	0.371	2.09 (9), 1.69 (45); 1.33 (3), 0.97 (4), 0.72 (22), 0.65 (9), 0.60 (92)	1666	9.3	19	4.1	57
¹²⁵I	60 d	EC, γ	–	–		0.035 (7) [0.027 (93) Te X rays]		0.67	1.35	–	57
¹³⁰I	12.3 h	β^-, γ	*1.02 (46), 0.60 (54)*	0.267	0.276	1.15 (31), 0.74 (69), 0.66 (100); 0.53 (100); 0.41 (23)	10.5	12.1	0.21	4.5	0.52
¹³¹I	8.09 d	β^-, γ	0.815 (0.7), 0.608 (87.2), 0.335 (9.3), 0.250 (2.8)	0.181	0.188	0.722 (3), 0.637 (9), 0.364 (80), 0.284 (5); 0.08 (2)	112.2	2.2	0.60	2.2	8.1
¹³²I	2.3 h	β^-, γ	2.22, 2.14 (81), 1.61 (21), 1.49 (12), 1.22 (12), 1.04 (15), 0.80 (21)			1.40 (8), 1.14 (4), 0.95 (19), 0.78 (82), 0.72 (7), 0.67 (99), 0.65 (26), 0.62 (5), 0.52 (19) and other weak lines		11.12	0.036	10.7	0.095
¹³²Te	78 h	β^-, γ	0.22 (100)			0.23 (92), 0.052 (~16)		12.74	1.4	0.5	3.28
¹³⁷Cs	30 y	β^-, γ	1.17 (8), 0.51 (92)	0.179	0.235	0.662 (84)	1900×10³	3.30	1.2×10³	5.0	10900
¹⁷⁰Tm	120 d	β^-, EC, γ	0.97 (77), 0.885 (23)	0.323	0.328	0.084 (9)	2860	0.08	0.3	4.0	156
¹⁸²Ta	113 d	β^-, γ	0.514 (52.1), 0.44 (34.3), 0.36 (14.6)	0.142	–	1.23, 1.22, 1.19, 1.12, 0.22, 0.15, 0.10, 0.07 and other weak lines	1183*	6.0	23	1.8	159
¹⁹²Ir	74.5 d	β^-, EC	0.67 (50), 0.54 (35), 0.26 (8), *0.097 (1)*	0.169	–	0.61, 0.60, 0.48, 0.47, 0.32, 0.31, 0.30, *and other weak lines*	930*	5.0	13	2.5	109
¹⁹⁷Hg	65.5 h	EC, γ	–	–	0.012	1.92 (1), 0.077 (28)	2.4	0.66	0.06	–	4.08
¹⁹⁸Au	2.7 d	β^-, γ	0.96 (98.6), 0.29 (1.4)	0.312	0.321	1.09 (0.3), 0.67 (1.2), 0.41 (97)	64.0	2.35	0.21	3.8	4.1
¹⁹⁹Au	3.15 d	β^-, γ	0.46 (6.4), 0.302 (69.3), 0.25 (24.3)	0.085	0.110	0.208 (16), 0.158 (77), 0.05 (0.6)	26.4	0.86	0.09	1.5	4.8
²⁰³Hg	46.5 d	β^-, γ	0.208 (100)	0.057	0.086	0.279 (86)	296	1.37	2.15	0.45	73.3
²⁰⁴Tl	4.1 y	β^-, EC	0.764 (98)	0.238	0.238	–	263×10³	0.007	0.35	2.9	2330

* β Rays only

References

[1] Modified from GLOCKER and MACHERAUCH, *Röntgen- und Kernphysik für Mediziner und Biophysiker*, 2nd ed., Thieme, Stuttgart, 1965, pages 39, 40, 42 and 238

[2] Values mainly from STROMINGER et al., *Rev. mod. Phys.*, 30, 585 (1958), and (where no value is given in column 6) *International Directory of Isotopes*, 3rd ed., International Atomic Energy Agency, Vienna, 1964

[3] WECHSELBERGER, E., Tübingen, personal communication, 1967

[4] Theoretical values for the carrier-free nuclides from E. KALLEE, Tübingen, 1967

Notes

Column 3 β^+ = positron emission, EC = orbital electron capture

Column 4 E_{max} = maximum β-energy in MeV + = positron emission. *Numbers in brackets are the frequencies of electron or positron emission as percentage of disintegrations.*

Column 5 $\bar{E}_\beta$ = mean value of the energies of all the β-rays emitted per disintegration. Calculated from E_{max} on the basis of theoretical data of L.H. MARSHALL (*Nucleonics*, 13, 34 [1955])

Column 6 $\bar{E}_\beta^{tot}$ = sum of $\bar{E}_\beta$, the K energy (from internal conversions and *electron capture*), *the energies of the conversion and* AUGER *electrons*, and the L and M energies. For nuclides with atomic numbers greater than 35, the K energy is usually included in calculating the γ dose. For ⁹⁰Sr, HINE has calculated a correction factor of 1.17 to take account of forbidden transitions

Column 7 The numbers in brackets are the frequencies of the transitions as percentage of disintegrations. Transitions with frequencies < 0.1% have been disregarded. Energies with a value of 0.51 MeV are annihilation radiations. The effect of internal conversions has been allowed for.

Column 8 Calculated from the equation given on page 286

Column 9 Calculated from the equation $\Gamma = 194 \times E_\gamma \times (\mu_K/\varrho)_L$ [R cm² h⁻¹ mCi⁻¹], (where E_γ = γ-energy and $[\mu_K/\varrho]_L$ = mass energy transfer coefficient for air), and including the K energy (from internal conversions and electron capture) for nuclides of atomic number greater than 35 (except for those for which no value is given in column 6). See also page 221

Column 10. Calculated from the equation given on page 286.

Column 12 Theoretical values for the carrier-free nuclides

Nuclide	Half-life	Mode of decay	β-Radiation E_{max}	β-Radiation $\bar{E}_\beta$	E_β^{tot}	γ-Radiation[2] (energies in MeV)	Dose constants K_β $\left[\frac{rd\,g}{\mu Ci}\right]$	Dose constants Γ $\left[\frac{R\,cm^2}{h\,mCi}\right]$	Dose constants K_γ[3] $\left[\frac{rd\,cm^2}{\mu Ci}\right]$	β-range in water[3] (mm)	Reciprocal specific activity[4] $\left[\frac{pg}{\mu Ci}\right]$
1	2	3	4	5	6	7	8	9	10	11	12
^{3}H	12.36 y	β^-	0.018 (100)	0.005_5	0.005_5	–	1835	–	–	0.007	103
^{14}C	5568 y	β^-	0.156 (100)	0.049_6	0.049_6	–	7450×10^3	–	–	0.24	218×10^3
^{22}Na	2.58 y	β^+, EC, γ	+0.54 (89)	0.188	0.188	1.28 (100); 0.51 (178)	13100	11.7	3.72×10^2	2.1	160
^{24}Na	15 h	β^-, γ	1.39 (100)	0.550	0.550	2.75 (100); 1.37 (100)	25.6	18.1	0.39	6.4	0.113
^{32}P	14.4 d	β^-	1.71 (100)	0.695	0.695	–	739	–	–	8.0	3.52
^{35}S	87.5 d	β^-	0.167 (100)	0.049	0.049	–	316	–	–	0.3	23.4
^{36}Cl	2.85×10^5 y	β^-, EC	0.71 (98)	0.247	0.247	–	1900×10^6	–	–	2.7	30.5×10^6
^{42}K	12.47 h	β^-, γ	3.55 (82); 1.98 (18)	1.469	1.469	1.53 (18)	56.3	1.35	0.024	19	0.167
^{45}Ca	159 d	β^-	0.258 (100)	0.078	0.078	–	915	–	–	0.6	56.6
^{47}Ca	4.7 d	β^-, γ	2.00 (18); 0.69 (82)			1.30 (76); 0.81 (6); 0.50 (6)		5.1	0.81	9.6	1.69
^{51}Cr	27.8 d	EC, γ	–	–	0.0049	0.32 (9)	10	0.18	0.17	–	10.9
^{52}Mn	5.67 d	β^+, EC, γ	+0.58 (34)	0.084_5	0.088	1.46 (100); 0.94 (100); 0.73 (100); 0.51 (68)	36.9	18.5	3.6	2.2	2.27
^{54}Mn	297 d	EC, γ	–	–	0.0054	0.84 (100)	118.7	4.7	47	–	122.6
^{55}Fe	2.77 y	EC	–	–	0.0059	–	441	–	–	–	414
^{57}Co	267 d	EC, γ	–	–		0.136 (9); 0.122 (89); 0.0144 (6)		0.61	5.5	–	118
^{58}Co	71 d	β^+, EC, γ	+0.49 (15)			1.6 (5); 0.81 (99.5); 0.51		5.585	13.4	1.5	31.6
^{59}Fe	45 d	β^-, γ	1.56 (0.3); 0.462 (54); 0.271 (46)	0.128	0.128	1.29 (43); 1.10 (57); 0.19 (3)	432	6.2	9.4	1.5	20.6
^{60}Co	5.23 y	β^-, γ	1.48 (0.2); 0.312 (99.8)	0.095	0.095	1.33 (100); 1.17 (100)	1340	12.9	8.32×10^2	0.8	884
^{61}Cu	12.8 h	β^-, β^+, EC, γ	0.57 (39); +0.65 (19)	0.126	0.130	1.35 (0.5); 0.51 (38)	5.1	1.15	0.021	2.6	0.226
^{65}Zn	245 d	β^+, EC, γ	+0.324 (1.5)	0.002	0.010	1.12 (46); 0.51 (3)	181	2.8	23	1.2	122
^{74}As	18 d	β^-, β^+, EC, γ	1.36 (17.7); 0.72 (14.5); +1.5 (3.6); +0.91 (26.1)			0.635 (14.5); 0.596 (61); 0.51		4.4	2.6	7.0	9.93
^{75}Se	120 d	EC, γ	–	–		0.405 (15); 0.308 (1); 0.281 (28); 0.269 (54); 0.20 (2); 0.136 (40); 0.122 (12); 0.097 (2); 0.066 (7) and other weak lines		1.5	6.1	–	69
^{76}As	26.45 h	β^-, γ	2.97 (50); 2.41 (31); 1.76 (16); 0.36 (3)	1.078	1.078	2.06 (2); 1.41 (1); 1.21 (12); 0.65 (5); 0.56 (38)	87.8	2.4	0.089	15.7	0.642
^{82}Br	35.7 h	β^-, γ	0.45 (100)	0.134	0.134	1.48 (17); 1.32 (28); 1.04 (27); 0.83 (27); 0.78 (83); 0.70 (27); 0.62 (44); 0.55 (73)	14.7	14.5	0.73	1.6	0.942
^{85}Kr	10.6 y	β^-, γ	0.672 (< 99.3); 0.15 (> 0.7)			0.514 (~0.7)		0.02	2.6	2.5	2520
^{86}Rb	18.66 d	β^-, γ	1.78 (84); 0.71 (15); 0.23 (1)	0.627	0.627	1.08 (9)	864	0.51	0.32	8.7	12.3
^{89}Sr	51.5 d	β^-	1.46 (100)	0.555	0.555	–	2260	–	–	6.8	34.7
^{90}Sr	28.0 y	β^-	0.54 (100)	0.174	0.174 (0.20)	–	(1510×10^3)	–	–	2.2	7050
^{90}Y	64.5 h	β^-	2.26 (100)	0.917	0.917	–	182	–	–	11	1.86
^{99}Mo	67 h	β^-, γ	1.23 (85); 0.87 (~1); 0.45 (14)			0.780 (4); 0.741 (10); 0.181 (2); 0.041 (1)		0.73	0.17	5.4	2.16

$^{99}Tc^{m}$	6 h	γ	–	–		0.142 (1), 0.140 (88)		0 67	0 0057	–	0 19
^{111}Ag	7 5 d	β^-, γ	1 04 (91), 0 80 (1), 0 70 (8)	0 356	0.356	0.34 (8), 0.24 (1)	197	0.17	0.043	4 0	6.35
^{113}Sn	119 d	EC, γ	–	–	0 120	0 39 (69)	1058	3.34	13	11 7	103
^{121}Te	17 d	EC, γ	–	–	0 009	0 57 (87) 0 51 (13), 0 07 (2)	6.3	4.4	2.5	–	15.7
^{124}Sb	60 5 d	β^-, γ	0 97 (9), 0 61 (49), 0 24 (14)	0.371	0 371	2.09 (9), 1 69 (45), 1.33 (3), 0 97 (4), 0 72 (22), 0 65 (9), 0 60 (92)	1666	9 3	19	4 1	57
^{125}I	60 d	EC, γ	–	–		0 035 (7) [0 027 (93) Te X rays]		0 67	1.35	–	57
^{130}I	12 5 h	β^-, γ	1 02 (46), 0 60 (54)	0 267	0.276	1.15 (31), 0 74 (69), 0 66 (100); 0.53 (100), 0.41 (23)	10 5	12 1	0 21	4.5	0.52
^{131}I	8.09 d	β^-, γ	0 815 (0 7), 0 608 (87 2), 0 335 (9 3), 0.250 (2.8)	0 181	0 188	0.722 (3), 0 637 (9), 0 364 (80), 0.284 (5), 0 08 (2)	112.2	2.2	0 60	2 2	8 1
^{132}I	2 3 h	β^-, γ	2.22, 2.14 (81), 1 61 (21), 1 49 (12), 1.22 (12), 1 04 (15), 0 80 (21)			1 40 (8), 1 14 (4), 0 95 (19), 0.78 (82), 0 72 (7), 0 67 (99), 0 65 (26), 0 62 (5); 0 52 (19) and other weak lines		11.12	0 036	10 7	0.095
^{132}Te	78 h	β^-, γ	0 22 (100)			0 23 (92), 0 052 (~16)		12.74	1 4	0.5	3 28
^{137}Cs	30 y	β^-, γ	1 17 (8), 0 51 (92)	0 179	0 235	0 662 (84)	1900×10^{3}	3.30	1.2×10^{3}	5 0	10900
^{170}Tm	120 d	β^-, EC, γ	0 97 (77), 0 885 (23)	0 323	0.328	0 084 (9)	2860	0 08	0 3	4 0	156
^{182}Ta	113 d	β^-, γ	0.514 (52.1), 0 44 (34 3), 0 36 (14 6)	0 142	–	1 23, 1 22, 1 19, 1 12, 0 22, 0.15, 0 10, 0 07 and other weak lines	1183*	6 0	23	1.8	159
^{192}Ir	74 5 d	β^-, EC	0 67 (50), 0 54 (35), 0 26 (8), 0 097 (1)	0 169	–	0 61, 0 60, 0 48, 0 47, 0 32, 0.31, 0 30, and other weak lines	930*	5 0	13	2.5	109
^{197}Hg	65 5 h	EC, γ	–	–	0 012	1 92 (1), 0 077 (28)	2.4	0.66	0 06	–	4 08
^{198}Au	2.7 d	β^-, γ	0 96 (98 6), 0 29 (1 4)	0 312	0.321	1 09 (0.3), 0.67 (1.2), 0 41 (97)	64 0	2.35	0.21	3 8	4.1
^{199}Au	3 15 d	β^-, γ	0 46 (6 4); 0 302 (69 3), 0 25 (24.3)	0 085	0.110	0.208 (16), 0 158 (77), 0 05 (0.6)	26 4	0 86	0 09	1 5	4.8
^{203}Hg	46 5 d	β^-, γ	0 208 (100)	0 057	0.086	0 279 (86)	296	1.37	2.15	0.45	73 3
^{204}Tl	4 1 y	β^-, EC	0.764 (98)	0 238	0 238	–	263×10^{3}	0 007	0.35	2.9	2330

* β Rays only

References

[1] Modified from Glocker and Macherauch, *Röntgen- und Kernphysik für Mediziner und Biophysiker*, 2nd ed., Thieme, Stuttgart, 1965, pages 39, 40, 42 and 238
[2] Values mainly from Strominger et al., *Rev mod Phys*, 30, 585 (1958), and (where no value is given in column 6) *International Directory of Isotopes*, 3rd ed., International Atomic Energy Agency, Vienna, 1964
[3] Wechselberger, E., Tübingen, personal communication, 1967
[4] Theoretical values for the carrier-free nuclides from E. Kallee, Tübingen, 1967.

Notes

Column 3 β^+ = positron emission, EC = orbital electron capture

Column 4 E_{max} = maximum β-energy in MeV + = positron emission. Numbers in brackets are the frequencies of electron or positron emission as percentage of disintegrations

Column 5 $\bar{E}_\beta$ = mean value of the energies of all the β-rays emitted per disintegration Calculated from E_{max} on the basis of theoretical data of I H Marshall (*Nucleonics*, 13, 34 [1955])

Column 6 E_β^{tot} = sum of $\bar{E}_\beta$, the K energy (from internal conversions and electron capture), the energies of the conversion and Auger electrons, and the L and M energies For nuclides with atomic numbers greater than 35, the K energy is usually included in calculating the γ dose. For ^{90}Sr, Hine has calculated a correction factor of 1 17 to take account of forbidden transitions

Column 7 The numbers in brackets are the frequencies of the transitions as percentage of disintegrations Transitions with frequencies < 0 1% have been disregarded. Energies with a value of 0 51 MeV are annihilation radiations. The effect of internal conversions has been allowed for

Column 8 Calculated from the equation given on page 286.

Column 9 Calculated from the equation $\Gamma = 194 \times E_\gamma \times (\mu_K/\varrho)_L$ [R cm² h⁻¹ mCi⁻¹], (where E_γ = γ-energy and $[\mu_K/\varrho]_L$ = mass energy transfer coefficient for air), and including the K energy (from internal conversions and electron capture) for nuclides of atomic number greater than 35 (except for those for which no value is given in column 6) See also page 221

Column 10 · Calculated from the equation given on page 286

Column 12 Theoretical values for the carrier-free nuclides.

Explanation of the tables on pages 294–306 *

Column 1 — t = elapsed time ($t - t_0$) in days (d), hours (h) and minutes (min).

Column 2 — N_t = amount of isotope not disintegrated at time t expressed as percentage of N_0 (the values apply equally to the activities A_t and A_0).

Columns 3 and 4 — Factors and their logarithms for calculating N_0 (or A_0) from N_t (or A_t):

$$N_0 = \frac{N_0}{N_t} N_t \quad \text{or} \quad A_0 = \frac{A_0}{A_t} A_t$$

The half-lives ($T_{1/2}$) of ^{99}Tc^{m}, ^{132}Te and ^{197}Hg are taken from the *Handbook of Chemistry and Physics*[1], all others from the *Catalogue of Radioactive Products*[2].

* Reproduction of data on pages 294–306 only by permission of the publishers of these *Scientific Tables*.

Decay data for ^{3}H and ^{226}Ra have also been calculated and may be obtained on application to the publishers of these *Scientific Tables*.

The data in the tables have been calculated by computer using the following relationships (see also page 217):

Column 2 $$\ln \frac{N_t}{N_0} = \frac{-\ln 2}{T_{1/2}}\, t$$

Columns 3 and 4 $$\ln \frac{N_0}{N_t} = \frac{\ln 2}{T_{1/2}}\, t$$

$$\left(\text{Disintegration constant } \lambda_t = \frac{\ln 2}{T_{1/2}}\right)$$

References

[1] Heath, R.L., in Weast et al. (Eds.), *Handbook of Chemistry and Physics*, 49th ed., The Chemical Rubber Co., Cleveland, 1968, page B-4.
[2] Radiochemical Centre, *Catalogue of Radioactive Products*, RC.11, Amersham, Bucks., 1967/68.

Sodium-22
half-life 2.6 y

t (d)	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.00000
50	96.42	1.037	0.01585
100	92.96	1.076	0.03170
150	89.63	1.116	0.04755
200	86.42	1.157	0.06340
250	83.32	1.200	0.07925
300	80.33	1.245	0.09510
400	74.68	1.339	0.12680
500	69.42	1.440	0.15850
600	64.54	1.550	0.19020
700	59.99	1.667	0.22190
800	55.77	1.793	0.25360
900	51.84	1.929	0.28530
1000	48.19	2.075	0.31700
1100	44.80	2.232	0.34870
1200	41.65	2.401	0.38040
1300	38.72	2.583	0.41210
1400	35.99	2.778	0.44380
1500	33.46	2.989	0.47550
1600	31.10	3.215	0.50720
1800	26.88	3.720	0.57060
2000	23.23	4.305	0.63400
2250	19.35	5.167	0.71325
2500	16.13	6.201	0.79250
2750	13.44	7.443	0.87175
3000	11.19	8.933	0.95100
3250	9.33	10.721	1.03025
3500	7.77	12.868	1.10949
3750	6.48	15.443	1.18874
4000	5.40	18.535	1.26799
4250	4.50	22.246	1.34724
4500	3.75	26.699	1.42649
4750	3.12	32.044	1.50574
5000	2.60	38.459	1.58499
5250	2.17	46.158	1.66424
5500	1.81	55.398	1.74349
5750	1.50	66.488	1.82274
6000	1.25	79.798	1.90199
6250	1.04	95.773	1.98124
6500	0.87	114.945	2.06049
6750	0.72	137.956	2.13974
7000	0.60	165.573	2.21899
7250	0.50	198.719	2.29824

Sodium-24
half-life 15 h

t d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
		0	100.00	1.000	0.00000
		10	99.23	1.007	0.00335
		20	98.47	1.015	0.00669
		30	97.72	1.023	0.01003
		40	96.97	1.031	0.01338
		50	96.22	1.039	0.01672
	1	0	95.48	1.047	0.02007
		10	94.75	1.055	0.02341
		20	94.02	1.063	0.02676
		30	93.30	1.071	0.03010
		40	92.59	1.080	0.03345
		50	91.88	1.088	0.03679
	2	0	91.17	1.096	0.04014
		10	90.47	1.105	0.04348
		20	89.78	1.113	0.04683
		30	89.09	1.122	0.05017
		40	88.41	1.131	0.05352
		50	87.73	1.139	0.05686
	3	0	87.06	1.148	0.06021
		10	86.39	1.157	0.06355
		20	85.72	1.166	0.06690
		30	85.07	1.175	0.07024
		40	84.41	1.184	0.07359
		50	83.77	1.193	0.07693
	4	0	83.12	1.203	0.08028
		10	82.49	1.212	0.08362
		20	81.85	1.221	0.08696
		30	81.23	1.231	0.09031
		40	80.60	1.240	0.09365
		50	79.98	1.250	0.09700
	5	0	79.37	1.259	0.10034
		10	78.76	1.269	0.10369
		20	78.16	1.279	0.10703
		30	77.56	1.289	0.11038
		40	76.96	1.299	0.11372
		50	76.37	1.309	0.11707
	6	0	75.79	1.319	0.12041
		10	75.20	1.329	0.12376
		20	74.63	1.339	0.12710
		30	74.05	1.350	0.13045
		40	73.49	1.360	0.13379
		50	72.92	1.371	0.13714
	7	0	72.36	1.381	0.14048
		10	71.81	1.392	0.14383
		20	71.26	1.403	0.14717
		30	70.71	1.414	0.15052
		40	70.17	1.425	0.15386
		50	69.63	1.436	0.15720
	8	0	69.10	1.447	0.16055
		10	68.57	1.458	0.16389
		20	68.04	1.469	0.16724
		30	67.52	1.481	0.17058
		40	67.00	1.492	0.17393
		50	66.49	1.504	0.17727
	9	0	65.98	1.515	0.18062
		10	65.47	1.527	0.18396
		20	64.97	1.539	0.18731
		30	64.47	1.551	0.19065
		40	63.97	1.563	0.19400
		50	63.48	1.575	0.19734
	10	0	63.00	1.587	0.20069
		10	62.51	1.599	0.20403
		20	62.03	1.612	0.20738
		30	61.56	1.624	0.21072
		40	61.08	1.637	0.21407
		50	60 62	1.649	0.21741
	11	0	60.15	1.662	0.22076
		10	59.69	1.675	0.22410
		20	59.23	1.688	0.22745
		30	58.78	1.701	0.23079
		40	58.33	1.714	0.23413
		50	57.88	1.727	0.23748
	12	0	57.43	1.741	0.24082
		10	56.99	1.754	0.24417
		20	56 56	1.768	0.24751
		30	56.12	1.781	0.25086
		40	55.69	1.795	0.25420
		50	55.27	1.809	0.25755
	13	0	54.84	1.823	0.26089
		10	54.42	1.837	0.26424
		20	54.00	1.851	0.26758
		30	53.59	1.866	0.27093
		40	53.18	1.880	0.27427
		50	52.77	1.895	0.27762
	14	0	52.36	1.909	0.28096
		10	51.96	1.924	0.28431
		20	51.56	1.939	0.28765
		30	51.17	1.954	0.29100
		40	50.78	1.969	0.29434
		50	50 39	1.984	0.29769
	15	0	50.00	2.000	0.30103
		10	49.62	2.015	0.30438
		20	49.24	2.031	0.30772
		30	48.86	2.046	0.31106
		40	48.48	2.062	0.31441
		50	48.11	2.078	0.31775
	16	0	47.74	2.094	0.32110
		10	47.38	2.110	0.32444
		20	47.01	2.127	0.32779
		30	46.65	2.143	0.33113
		40	46.29	2.160	0.33448
		50	45.94	2.176	0.33782
	17	0	45.59	2.193	0.34117
		10	45.24	2.210	0.34451
		20	44.89	2.227	0.34786
		30	44.54	2.244	0.35120
		40	44.20	2.262	0.35455
		50	43.86	2.279	0.35789
	18	0	43.53	2 297	0.36124
		10	43.19	2.315	0.36458
		20	42.86	2.333	0.36793
		30	42.53	2.351	0.37127
		40	42.21	2.369	0.37462
		50	41.88	2.387	0.37796
	19	0	41.56	2.406	0.38131
		10	41.24	2.424	0.38465
		20	40.93	2.443	0.38799
		30	40.61	2.462	0.39134
		40	40.30	2.481	0.39468
		50	39.99	2.500	0.39803
	20	0	39.69	2.519	0.40137
		10	39.38	2.539	0.40472
		20	39.08	2.558	0.40806
		30	38.78	2.578	0.41141
		40	38.48	2.598	0.41475
		50	38.19	2.618	0.41810
	21	0	37.89	2.639	0.42144
		10	37.60	2.659	0.42479
		20	37.31	2.679	0.42813
		30	37.03	2.700	0.43148
		40	36.74	2.721	0.43482
		50	36.46	2.742	0.43817
	22	0	36.18	2.763	0.44151
		10	35.90	2.785	0.44486
		20	35.63	2.806	0.44820
		30	35.36	2.828	0.45155
		40	35.08	2.850	0.45489
		50	34.81	2 872	0 45823
	23	0	34.55	2 894	0.46158
		10	34.28	2.916	0.46492
		20	34.02	2.939	0.46827
		30	33.76	2.962	0.47161
		40	33.50	2.985	0.47496
		50	33.24	3 008	0.47830
1	0		32.99	3.031	0.48165
	1		31.50	3.174	0.50172
	2		30.08	3.324	0.52179
	3		28.72	3.482	0.54185
	4		27.42	3.646	0.56192
	5		26 18	3 819	0.58199
	6		25.00	3 999	0.60206
	7		23.87	4.189	0 62213
	8		22.79	4.387	0.64220
	9		21.76	4.594	0.66227
	10		20.78	4.812	0.68233
	11		19.84	5.039	0.70240
	12		18.95	5.278	0.72247
	13		18 09	5.527	0.74254
	14		17.27	5.789	0.76261
	15		16.49	6 062	0.78268
	16		15.75	6.349	0.80274
	17		15 04	6 649	0 82281
	18		14.36	6.964	0.84288
	19		13.71	7.293	0.86295
	20		13.09	7.638	0.88302
	21		12.50	7.999	0 90308
	22		11.94	8.378	0.92315
	23		11.40	8.774	0.94322
2	0		10.88	9.189	0.96329
	1		10.39	9.623	0.98335
	2		9.92	10.079	1.00343
	3		9.47	10.556	1.02350
	4		9.05	11.055	1.04357
	5		8.64	11.578	1.06364
	6		8.25	12.125	1.08371
	7		7.87	12.699	1.10378
	8		7.52	13.299	1.12385
	9		7.18	13.928	1.14391
	10		6.86	14.587	1.16398
	11		6.55	15.277	1.18405
	12		6.25	16.000	1.20412
	13		5.97	16.756	1.22419
	14		5.70	17.549	1.24426
	15		5.44	18.379	1.26433
	16		5.20	19.248	1.28439
	17		4.96	20.158	1.30446
	18		4.74	21.112	1.32453
	19		4.52	22.110	1.34460
	20		4.32	23.156	1.36467
	21		4.12	24 251	1.38474
	22		3.94	25.398	1.40481
	23		3.76	26.599	1.42488
3	0		3.59	27.857	1.44494
	1		3.43	29.175	1.46501
	2		3.27	30.554	1.48508
	3		3.13	32.000	1.50515
	4		2.98	33.513	1.52522
	5		2.85	35.098	1.54529
	6		2.72	36.758	1.56536
	7		2.60	38.496	1.58542
	8		2.48	40.317	1.60549
	9		2.37	42.224	1.62556
	10		2.26	44.221	1.64563
	11		2.16	46.312	1.66570
	12		2.06	48.502	1.68577
	13		1.97	50.796	1.70584
	14		1.88	53.199	1.72590
	15		1.79	55.714	1.74597
	16		1.71	58.349	1.76604
	17		1.64	61.109	1.78611
	18		1.56	63.999	1.80618
	19		1.49	67.026	1.82625
	20		1.42	70.196	1.84631
	21		1.36	73.515	1.86638
	22		1.30	76.992	1.88645
	23		1 24	80.634	1.90652
4	0		1.18	84.447	1.92659
	1		1.13	88.440	1.94665
	2		1.08	92.623	1.96672
	3		1.03	97.003	1.98679
	4		0 98	101.594	2 00687
	5		0.94	106.398	2.02694
	6		0.90	111.430	2.04700
	7		0 86	116.701	2 06708
	8		0 82	122 219	2.08714
	9		0.78	128 000	2.10721
	10		0.75	134.053	2.12728
	11		0.71	140.394	2.14735
	12		0.68	147.032	2.16741
	13		0.65	153.988	2 18749
	14		0.62	161.269	2 20755
	15		0.59	168.896	2.22762
	16		0.57	176.884	2 24769
	17		0.54	185 250	2.26776
	18		0 52	194 012	2 28783
	19		0.49	203.185	2.30789
	20		0 47	212.797	2.32797
	21		0.45	222.861	2 34803
	22		0 43	233.399	2.36810
	23		0.41	244.439	2 38817

Phosphorus-32

half-life 14.3 d

t: d	t: h	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0	100.00	1.000	0.00000
	3	99.40	1.006	0.00263
	6	98.80	1.012	0.00526
	9	98.20	1.019	0.00789
	12	97.61	1.025	0.01053
	15	97.02	1.031	0.01316
	18	96.43	1.037	0.01579
	21	95.85	1.043	0.01842
1	0	95.27	1.050	0.02105
	12	92.99	1.075	0.03158
2	0	90.76	1.102	0.04210
	12	88.59	1.129	0.05263
3	0	86.47	1.157	0.06315
	12	84.40	1.185	0.07368
4	0	82.38	1.214	0.08420
	12	80.40	1.244	0.09473
5	0	78.48	1.274	0.10526
	12	76.60	1.306	0.11578
6	0	74.76	1.338	0.12631
	12	72.97	1.370	0.13683
7	0	71.23	1.404	0.14736
	12	69.52	1.439	0.15788
8	0	67.86	1.474	0.16841
	12	66.23	1.510	0.17893
9	0	64.65	1.547	0.18946
	12	63.10	1.585	0.19999
10	0	61.59	1.624	0.21051
	12	60.11	1.664	0.22104
11	0	58.67	1.704	0.23156
	12	57.27	1.746	0.24209
12	0	55.90	1.789	0.25261
	12	54.56	1.833	0.26314
13	0	53.25	1.878	0.27366
	12	51.98	1.924	0.28419
14	0	50.73	1.971	0.29472
	12	49.52	2.019	0.30524
15	0	48.33	2.069	0.31577
	12	47.17	2.120	0.32629
16		46.04	2.172	0.33682
17		43.87	2.280	0.35787
18		41.79	2.393	0.37892
19		39.81	2.512	0.39997
20		37.93	2.636	0.42102
21		36.13	2.767	0.44207
22		34.43	2.905	0.46312
23		32.80	3.049	0.48418
24		31.24	3.201	0.50523
25		29.77	3.360	0.52628
26		28.36	3.526	0.54733
27		27.02	3.702	0.56838
28		25.74	3.885	0.58943
29		24.52	4.078	0.61048
30		23.36	4.281	0.63153
32		21.20	4.717	0.67364
34		19.24	5.197	0.71574
36		17.46	5.726	0.75784
38		15.85	6.309	0.79994
40		14.39	6.951	0.84205
42		13.06	7.659	0.88415
44		11.85	8.438	0.92625
46		10.76	9.297	0.96835
48		9.76	10.244	1.01045
50		8.86	11.286	1.05256
52		8.04	12.435	1.09466
54		7.30	13.701	1.13676
56		6.62	15.096	1.17886
58		6.01	16.633	1.22097
60		5.46	18.326	1.26307
65		4.29	23.352	1.36832
70		3.36	29.756	1.47358
75		2.64	37.917	1.57884
80		2.07	48.316	1.68409
85		1.62	61.567	1.78935
90		1.27	78.452	1.89460
100		0.79	127.384	2.10511
110		0.48	206.835	2.31562

Sulphur-35

half-life 87.2 d

t: d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.00000
5	96.10	1.041	0.01726
10	92.36	1.083	0.03452
15	88.76	1.127	0.05178
20	85.30	1.172	0.06904
25	81.98	1.220	0.08630
30	78.78	1.269	0.10357
35	75.71	1.321	0.12083
40	72.76	1.374	0.13809
50	67.20	1.488	0.17261
60	62.07	1.611	0.20713
70	57.33	1.744	0.24165
80	52.94	1.889	0.27618
90	48.90	2.045	0.31070
100	45.16	2.214	0.34522
110	41.71	2.397	0.37974
120	38.52	2.596	0.41426
130	35.58	2.811	0.44879
140	32.86	3.043	0.48331
150	30.35	3.295	0.51783
160	28.03	3.567	0.55235
180	23.91	4.182	0.62139
200	20.40	4.903	0.69044
225	16.72	5.981	0.77674
250	13.71	7.295	0.86305
275	11.24	8.899	0.94935
300	9.21	10.856	1.03566
325	7.55	13.242	1.12196
350	6.19	16.154	1.20827
375	5.07	19.705	1.29457
400	4.16	24.037	1.38088
425	3.41	29.321	1.46718
450	2.80	35.767	1.55349
475	2.29	43.631	1.63979
500	1.88	53.223	1.72610
525	1.54	64.923	1.81240
550	1.26	79.197	1.89871
575	1.04	96.608	1.98501
600	0.85	117.846	2.07132
625	0.70	143.754	2.15762
650	0.57	175.358	2.24393

Potassium-42

half life 12.4 h

t: d	t: h	t: min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0	0	100.00	1.000	0.00000
		10	99.07	1.009	0.00405
		20	98.15	1.019	0.00809
		30	97.24	1.028	0.01214
		40	96.34	1.038	0.01618
		50	95.45	1.048	0.02023
	1	0	94.56	1.057	0.02428
		10	93.69	1.067	0.02832
		20	92.82	1.077	0.03237
		30	91.96	1.087	0.03642
		40	91.10	1.098	0.04046
		50	90.26	1.108	0.04451
	2	0	89.42	1.118	0.04855
		10	88.59	1.129	0.05260
		20	87.77	1.139	0.05665
		30	86.96	1.150	0.06069
		40	86.15	1.161	0.06474
		50	85.35	1.172	0.06878
	3	0	84.56	1.183	0.07283
		10	83.78	1.194	0.07688
		20	83.00	1.205	0.08092
		30	82.23	1.216	0.08497
		40	81.47	1.227	0.08901
		50	80.71	1.239	0.09306
	4	0	79.96	1.251	0.09711
		10	79.22	1.262	0.10115
		20	78.49	1.274	0.10520
		30	77.76	1.286	0.10925
		40	77.04	1.298	0.11329
		50	76.32	1.310	0.11734
	5	0	75.62	1.322	0.12138
		10	74.92	1.335	0.12543
		20	74.22	1.347	0.12948
		30	73.53	1.360	0.13352
		40	72.85	1.373	0.13757
		50	72.17	1.386	0.14161
	6	0	71.51	1.398	0.14566
		10	70.84	1.412	0.14971
		20	70.19	1.425	0.15375
		30	69.53	1.438	0.15780
		40	68.89	1.452	0.16184
		50	68.24	1.465	0.16589
	7	0	67.62	1.479	0.16994
		10	66.99	1.493	0.17398
		20	66.37	1.507	0.17803
		30	65.75	1.521	0.18208
		40	65.14	1.535	0.18612
		50	64.54	1.549	0.19017
	8	0	63.94	1.564	0.19421
		10	63.35	1.579	0.19826
		20	62.76	1.593	0.20231
		30	62.18	1.608	0.20635
		40	61.60	1.623	0.21040
		50	61.03	1.638	0.21444
	9	0	60.47	1.654	0.21849
		10	59.91	1.669	0.22254
		20	59.35	1.685	0.22658
		30	58.80	1.701	0.23063
		40	58.25	1.717	0.23467
		50	57.71	1.733	0.23872
	10	0	57.18	1.749	0.24277
		10	56.65	1.765	0.24681
		20	56.12	1.782	0.25086
		30	55.60	1.798	0.25491
		40	55.09	1.815	0.25895
		50	54.58	1.832	0.26300
	11	0	54.07	1.849	0.26704
		10	53.57	1.867	0.27109
		20	53.07	1.884	0.27514
		30	52.58	1.902	0.27918
		40	52.09	1.920	0.28323
		50	51.61	1.938	0.28727
	12	0	51.13	1.956	0.29132
		20	50.19	1.993	0.29941
		40	49.26	2.030	0.30750
	13	0	48.35	2.068	0.31560
		20	47.46	2.107	0.32369
		40	46.58	2.147	0.33178
	14	0	45.72	2.187	0.33987
		20	44.88	2.228	0.34797
		40	44.05	2.270	0.35606
	15	0	43.24	2.313	0.36415
		20	42.44	2.356	0.37224
		40	41.65	2.401	0.38034
	16	0	40.89	2.446	0.38843
		20	40.13	2.492	0.39652
		40	39.39	2.539	0.40461
	17	0	38.66	2.586	0.41270
		20	37.95	2.635	0.42080
		40	37.25	2.685	0.42889
	18	0	36.56	2.735	0.43698
		20	35.89	2.787	0.44507
		40	35.22	2.839	0.45317
	19	0	34.57	2.892	0.46126
		20	33.94	2.947	0.46935
		40	33.31	3.002	0.47744
	20	0	32.69	3.059	0.48553
		20	32.09	3.116	0.49363
		40	31.50	3.175	0.50172
	21	0	30.92	3.235	0.50981
		20	30.35	3.295	0.51790
		40	29.79		
	22	0	29.24		
		20	28.70		
		40	28.17		
	23	0	27.65		
		20	27.14		
		40	26.63		
1	0	0	26.14	3.825	0.58264
		20	25.66	3.897	0.59073
		40	25.19	3.970	0.59883
	1	0	24.72	4.045	0.60692
		20	24.27	4.121	0.61501
		40	23.82	4.199	0.62310
	2	0	23.39	4.278	0.63119
		20	22.95	4.358	0.63929
		40	22.52	4.440	0.64738
	3	0	22.11	4.523	0.65547
		20	21.70	4.609	0.66356
		40	21.30	4.695	0.67166
	4	0	20.91	4.784	0.67975
		20	20.52	4.873	0.68784
		40	20.14	4.965	0.69593
	5	0	19.77	5.059	0.70402
		20	19.40	5.154	0.71212
		40	19.05	5.251	0.72021
	6	0	18.69	5.349	0.72830
		20	18.35	5.450	0.73639
		40	18.01	5.552	0.74449
	7	0	17.68	5.657	0.75258
		20	17.35	5.763	0.76067
		40	17.03	5.872	0.76876
	8	0	16.72	5.982	0.77685
		20	16.41	6.095	0.78495
		40	16.11	6.209	0.79304
	9	0	15.81	6.326	0.80113
		20	15.52	6.445	0.80922
		40	15.23	6.566	0.81732
	10	0	14.95	6.690	0.82541
		20	14.67	6.816	0.83350
		40	14.40	6.944	0.84159
	11	0	14.14	7.074	0.84968
		20	13.87	7.207	0.85778
		40	13.62	7.343	0.86587
	12		13.37	7.481	0.87396
	13		12.64	7.911	0.89824
	14		11.95	8.366	0.92252
	15		11.30	8.847	0.94679
	16		10.69	9.356	0.97107
	17		10.11	9.893	0.99535
	18		9.56	10.462	1.01962
	19		9.04	11.064	1.04390
	20		[illegible]	[illegible]	[illegible]
	21		8.08	12.372	[illegible]
	22		7.64	13.084	[illegible]
	23		7.23	13.836	[illegible]
2	0		6.83	14.631	[illegible]
	1		6.46	15.472	[illegible]
	2		6.11	16.362	[illegible]
	3		5.78	17.303	[illegible]
	4		5.47	18.297	[illegible]
	5		5.17	19.349	[illegible]
	6		4.89	20.462	[illegible]
	7		4.62	21.638	[illegible]
	8		4.37	22.882	[illegible]
	9		4.13	24.198	[illegible]
	10		3.91	25.589	[illegible]
	11		3.70	27.060	[illegible]
	12		3.49	28.616	[illegible]
	13		3.30	30.261	[illegible]
	14		3.12	32.000	[illegible]
	15		2.96	33.840	[illegible]
	16		2.79	35.786	[illegible]
	17		2.64	37.843	[illegible]
	18		2.50	40.019	[illegible]
	19		2.36	42.319	[illegible]
	20		2.23	44.752	[illegible]
	21		2.11	47.325	[illegible]
	22		2.00	50.046	[illegible]
	23		1.89	52.923	[illegible]
3	0		1.79	55.966	[illegible]
	1		1.69	59.183	[illegible]
	2		1.60	62.586	[illegible]
	3		1.51	66.184	[illegible]
	4		1.43	69.989	[illegible]
	5		1.35	74.013	[illegible]
	6		1.28	78.268	[illegible]
	7		1.21	82.768	[illegible]
	8		1.14	87.526	[illegible]
	9		1.08	92.558	[illegible]
	10		1.02	97.879	[illegible]
	11		0.97	103.506	[illegible]
	12		0.91	109.457	[illegible]
	13		0.86	115.750	[illegible]
	14		0.82	122.404	[illegible]
	15		0.77	129.442	[illegible]
	16		0.73	136.883	[illegible]
	17		0.69	144.753	[illegible]

Calcium-45

half life 165 d

d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	[illegible]
10	95.89	1.043	[illegible]
20	91.94	1.088	[illegible]
30	88.16	1.134	[illegible]
40	84.53	1.183	[illegible]
50	81.05	1.234	[illegible]
60	77.72	1.287	[illegible]
70	74.52	1.342	[illegible]
80	71.46	1.399	[illegible]
90	68.52	1.459	[illegible]
100	65.70	1.522	[illegible]
110	63.00	1.587	[illegible]
120	60.40	1.656	[illegible]
130	57.92	1.727	[illegible]
140	55.54	1.801	[illegible]
150	53.25	1.878	[illegible]
160	51.06	1.958	[illegible]
180	46.95	2.130	[illegible]
200	43.16	2.317	[illegible]
220	39.68	2.520	[illegible]
240	36.49	2.741	[illegible]
260	33.55	2.981	[illegible]
280	30.84	3.242	[illegible]
300	28.36	3.526	[illegible]
320	26.07	3.835	[illegible]
340	23.97	4.172	[illegible]
360	22.04	4.537	[illegible]
380	20.26	4.935	[illegible]
400	18.63	5.368	[illegible]
425	16.77	5.962	[illegible]
450	15.10	6.622	[illegible]
475	13.60	7.355	[illegible]
500	12.24	8.170	[illegible]
525	11.02	9.075	[illegible]
550	9.92	10.079	[illegible]
575	8.93	11.196	[illegible]
600	8.04	12.435	[illegible]
625	7.24	13.812	[illegible]
650	6.52	15.342	[illegible]
675	5.87	17.041	[illegible]

N_t	N_0/N_t	$\log_{10} N_0/N_t$
4.76	21.024	1.32271
4.28	23.352	1.36832
3.86	25.938	1.41393
3.47	28.810	1.45955
2.81	35.544	1.55077
2.28	43.852	1.64199
1.85	54.102	1.73321
1.50	66.747	1.82443
1.21	82.348	1.91565
0.98	101.596	2.00687
0.80	125.342	2.09810
0.65	154.639	2.18932
0.52	190.783	2.28054

Calcium-47
half-life 4.7 d

t (d)	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	100.00	1.000	0.00000
	98.17	1.019	0.00801
	96.38	1.038	0.01601
	94.62	1.057	0.02402
	92.89	1.077	0.03202
	91.19	1.097	0.04003
	89.53	1.117	0.04804
	87.89	1.138	0.05604
	86.29	1.159	0.06405
	84.71	1.180	0.07206
	83.16	1.202	0.08006
	81.65	1.225	0.08807
	80.15	1.248	0.09607
	78.69	1.271	0.10408
	77.25	1.294	0.11209
	75.84	1.319	0.12009
	74.46	1.343	0.12810
	73.10	1.368	0.13610
	71.76	1.394	0.14411
	70.45	1.419	0.15212
	69.16	1.446	0.16012
	67.90	1.473	0.16813
	66.66	1.500	0.17614
	65.44	1.528	0.18414
	64.25	1.556	0.19215
	63.07	1.585	0.20015
	61.92	1.615	0.20816
	60.79	1.645	0.21617
	59.68	1.676	0.22417
	58.59	1.707	0.23218
	57.52	1.739	0.24018
	56.47	1.771	0.24819
	55.44	1.804	0.25620
	54.42	1.837	0.26420
	53.43	1.872	0.27221
	52.45	1.906	0.28022
	51.50	1.942	0.28822
	50.56	1.978	0.29623
	49.63	2.015	0.30423
	48.73	2.052	0.31224
	47.84	2.090	0.32025
	46.96	2.129	0.32825
	46.10	2.169	0.33626
	45.26	2.209	0.34426
	44.44	2.250	0.35227
	43.62	2.292	0.36028
	42.83	2.335	0.36828
	42.04	2.378	0.37629
	41.28	2.423	0.38430
	40.52	2.468	0.39230
	39.78	2.514	0.40031
	39.06	2.560	0.40831
	38.34	2.608	0.41632
	37.64	2.657	0.42433
	36.95	2.706	0.43233
	36.28	2.756	0.44034
	35.62	2.808	0.44834
	34.97	2.860	0.45635
	34.33	2.913	0.46436
	33.70	2.967	0.47236
	33.08	3.023	0.48037
	32.48	3.079	0.48838
	31.89	3.136	0.49638
	31.30	3.194	0.50439
	30.73	3.254	0.51239
	28.55	3.503	0.54442
	26.52	3.771	0.57644
	24.63	4.059	0.60847
	22.88	4.370	0.64049
	21.26	4.705	0.67252
	19.75	5.065	0.70454
	18.34	5.452	0.73657
	17.04	5.869	0.76859
	15.83	6.319	0.80061
	14.70	6.802	0.83264
	13.66	7.323	0.86466
	12.69	7.883	0.89669
	10.95	9.136	0.96074
16	9.45	10.587	1.02479
17	8.15	12.270	1.08884
18	7.03	14.220	1.15289
19	6.07	16.479	1.21693
20	5.24	19.098	1.28098
22	3.90	25.650	1.40908
24	2.90	34.449	1.53718
26	2.16	46.268	1.66528
28	1.61	62.141	1.79338
30	1.20	83.460	1.92148
32	0.89	112.092	2.04957
34	0.66	150.547	2.17767
36	0.49	202.195	2.30577

Chromium-51
half-life 27.8 d

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100.00	1.000	0.00000
	6		99.38	1.006	0.00271
	12		98.76	1.013	0.00541
	18		98.15	1.019	0.00812
1	0		97.54	1.025	0.01083
	6		96.93	1.032	0.01354
	12		96.33	1.038	0.01624
	18		95.73	1.045	0.01895
2	0		95.14	1.051	0.02166
	12		93.96	1.064	0.02707
3	0		92.79	1.078	0.03249
	12		91.64	1.091	0.03790
4	0		90.51	1.105	0.04331
	12		89.39	1.119	0.04873
5	0		88.28	1.133	0.05414
	12		87.19	1.147	0.05956
6	0		86.11	1.161	0.06497
	12		85.04	1.176	0.07038
7	0		83.98	1.191	0.07580
	12		82.94	1.206	0.08121
8	0		81.92	1.221	0.08663
	12		80.90	1.236	0.09204
9	0		79.90	1.252	0.09746
	12		78.91	1.267	0.10287
10	0		77.93	1.283	0.10828
	12		76.97	1.299	0.11370
11	0		76.01	1.316	0.11911
	12		75.07	1.332	0.12453
12	0		74.14	1.349	0.12994
	12		73.22	1.366	0.13536
13	0		72.32	1.383	0.14077
	12		71.42	1.400	0.14618
14	0		70.53	1.418	0.15160
	12		69.66	1.436	0.15701
15	0		68.80	1.454	0.16243
	12		67.95	1.472	0.16784
16	0		67.10	1.490	0.17326
	12		66.27	1.509	0.17867
17	0		65.45	1.528	0.18408
	12		64.64	1.547	0.18950
18	0		63.84	1.566	0.19491
	12		63.05	1.586	0.20033
19	0		62.27	1.606	0.20574
	12		61.50	1.626	0.21115
20	0		60.73	1.647	0.21657
	12		59.98	1.667	0.22198
21	0		59.24	1.688	0.22740
	12		58.50	1.709	0.23281
22	0		57.78	1.731	0.23823
	12		57.06	1.752	0.24364
23	0		56.36	1.774	0.24905
	12		55.66	1.797	0.25447
24	0		54.97	1.819	0.25988
	12		54.29	1.842	0.26530
25	0		53.62	1.865	0.27071
	12		52.95	1.889	0.27613
26	0		52.29	1.912	0.28154
	12		51.65	1.936	0.28695
27	0		51.01	1.961	0.29237
	12		50.38	1.985	0.29778
28	0		49.75	2.010	0.30320
	12		49.13	2.035	0.30861
29	0		48.53	2.061	0.31403
	12		47.92	2.087	0.31944
30			47.33	2.113	0.32485
31			46.17	2.166	0.33568
32			45.03	2.221	0.34651
33			43.92	2.277	0.35734
34			42.84	2.334	0.36817
35			41.78	2.393	0.37900
36			40.75	2.454	0.38982
37			39.75	2.516	0.40065
38			38.77	2.579	0.41148
39			37.82	2.644	0.42231
40			36.89	2.711	0.43314
41			35.98	2.780	0.44397
42			35.09	2.850	0.45480
43			34.23	2.922	0.46562
44			33.38	2.995	0.47645
45			32.56	3.071	0.48728
46			31.76	3.149	0.49811
47			30.98	3.228	0.50894
48			30.22	3.310	0.51977
49			29.47	3.393	0.53059
50			28.75	3.479	0.54142
51			28.04	3.567	0.55225
52			27.35	3.657	0.56308
53			26.67	3.749	0.57391
54			26.02	3.844	0.58474
55			25.38	3.941	0.59557
56			24.75	4.040	0.60639
57			24.14	4.142	0.61722
58			23.55	4.247	0.62805
59			22.97	4.354	0.63888
60			22.40	4.464	0.64971
62			21.31	4.692	0.67136
64			20.28	4.932	0.69302
66			19.29	5.184	0.71468
68			18.35	5.449	0.73634
70			17.46	5.728	0.75799
72			16.61	6.021	0.77965
74			15.80	6.329	0.80131
76			15.03	6.652	0.82296
78			14.30	6.992	0.84462
80			13.61	7.350	0.86628
82			12.94	7.726	0.88793
84			12.31	8.121	0.90959
86			11.72	8.536	0.93125
88			11.15	8.972	0.95290
90			10.60	9.431	0.97456
92			10.09	9.913	0.99622
94			9.60	10.420	1.01788
96			9.13	10.953	1.03953
98			8.69	11.513	1.06119
100			8.26	12.102	1.08285
105			7.29	13.708	1.13699
110			6.44	15.529	1.19113
115			5.68	17.590	1.24527
120			5.02	19.926	1.29942
125			4.43	22.571	1.35356
130			3.91	25.568	1.40770
135			3.45	28.963	1.46184
140			3.05	32.808	1.51598
145			2.69	37.164	1.57013
150			2.38	42.099	1.62427
155			2.10	47.688	1.67841
160			1.85	54.020	1.73255
165			1.63	61.192	1.78670
170			1.44	69.317	1.84084
175			1.27	78.520	1.89498
180			1.12	88.945	1.94912
185			0.99	100.755	2.00327
190			0.88	114.132	2.05741
195			0.77	129.286	2.11155
200			0.68	146.451	2.16569
205			0.60	165.895	2.21983
210			0.53	187.922	2.27398
215			0.47	212.872	2.32812

Manganese-52
half-life 5.7 d

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100.00	1.000	0.00000
	6		97.01	1.030	0.01320
	12		94.10	1.062	0.02641
	18		91.28	1.095	0.03961
1	0		88.55	1.129	0.05281
	6		85.90	1.164	0.06602
	12		83.33	1.200	0.07922
	18		80.83	1.237	0.09242
2	0		78.41	1.275	0.10563
	6		76.06	1.314	0.11883
	12		73.79	1.355	0.13203
	18		71.58	1.397	0.14523
3	0		69.43	1.440	0.15844
	6		67.35	1.484	0.17164
	12		65.34	1.530	0.18484
	18		63.38	1.577	0.19805
4	0		61.48	1.626	0.21125
	6		59.64	1.676	0.22445
	12		57.86	1.728	0.23766
	18		56 12	1.781	0.25086
5			54.44	1.836	0.26406
6			48.21	2.074	0.31687
7			42.69	2.342	0.36969
8			37.80	2.645	0.42250
9			33.47	2.987	0.47531
10			29.64	3.373	0.52812
11			26.25	3.810	0.58094
12			23.24	4.302	0 63375
13			20.58	4.859	0.68656
14			18.22	5.487	0.73937
15			16.14	6.197	0.792
16			14.29	6.998	0.844
17			12.65	7.903	0.897
18			11.20	8.925	0.950
19			9.92	10.079	1.003
20			8.79	11.382	1.056
25			4.78	20.907	1.320
30			2.60	38.403	1.584
35			1.42	70.538	1.848
40			0.77	129.565	2.1124
45			0.42	237.987	2.3765
50			0.23	437.139	2.6406

Manganese-54
half-life 314 d

d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.0000
10	97.82	1.022	0.0095
20	95.68	1.045	0.0191
30	93.59	1.068	0.0287
40	91.55	1.092	0.0383
50	89.55	1.117	0.0479
60	87.59	1.142	0.0575
70	85.68	1.167	0.06711
80	83.81	1.193	0.07670
90	81.98	1.220	0.08628
100	80.19	1.247	0.09587
110	78.44	1.275	0.10546
120	76.73	1.303	0.11504
130	75.05	1.332	0.12463
140	73.41	1.362	0.13422
150	71.81	1.393	0.14380
160	70.24	1.424	0.15339
170	68.71	1.455	0.16298
180	67.21	1.488	0.17257
190	65.74	1.521	0.18215
200	64.31	1.555	0.19174
210	62.90	1.590	0.20133
220	61.53	1.625	0.21091
230	60.19	1.662	0.22050
240	58.87	1.699	0.23009
250	57.59	1.736	0.23967
260	56.33	1.775	0.24926
270	55.10	1.815	0.25885
280	53.90	1.855	0.26844
290	52.72	1.897	0.27802
300	51.57	1.939	0.28761
320	49.34	2.027	0.30678
340	47.21	2.118	0.32596
360	45.17	2.214	0.34513
380	43.22	2.314	0.36431
400	41.35	2.418	0.38348
420	39.57	2.527	0.40265
440	37.86	2.641	0.42183
460	36.22	2.761	0.44100
480	34.66	2.885	0.46018
500	33.16	3.015	0.47935
520	31.73	3.152	0.49852
540	30.36	3.294	0.51770
560	29.05	3.442	0.53687
580	27.79	3.598	0.55604
600	26.59	3.760	0.57522
640	24.35	4.107	0.61357
680	22.29	4.487	0.65191
720	20.41	4.901	0.69026
760	18.68	5.353	0.72861
800	17.10	5.847	0.76696
840	15.66	6.387	0.80531
880	14.33	6.977	0.84365
920	13.12	7.621	0.88200
960	12.01	8 324	0.92035
1000	11.00	9.093	0.95870
1100	8.82	11.339	1.05457
1200	7.07	14.140	1.15044
1300	5.67	17.632	1.24631
1400	4.55	21.988	1.34218
1500	3.65	27.419	1.43805
1700	2.35	42.637	1.62979
1900	1.51	66.302	1.82153
2000	1.21	82.679	1.91740
2500	0.40	249.313	2.39675

Iron-59
half-life 45 d

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100.00	1.000	0.00000
	12		99.23	1.007	0.00335
1	0		98.47	1.015	0 00669
	12		97.72	1.023	0.01003
2	0		96.97	1 031	0 01338
	12		96 22	1.039	0 01672

t d	t h	t min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
3	0		95 48	1 047	0 02007
	12		94 75	1 055	0 02341
4	0		94 02	1 063	0 02676
	12		93 30	1 071	0 03010
5	0		92 59	1 080	0 03345
	12		91 88	1 088	0 03679
6	0		91 17	1 096	0 04014
	12		90 47	1 105	0 04348
7	0		89 78	1 113	0 04683
	12		89 09	1 122	0 05017
8	0		88 41	1 131	0 05352
	12		87 73	1 139	0 05686
9	0		87 06	1 148	0 06021
	12		86 39	1 157	0 06355
10	0		85 72	1 166	0 06690
	12		85 07	1 175	0 07024
11	0		84 41	1 184	0 07359
	12		83 77	1 193	0 07693
12	0		83 12	1 203	0 08028
	12		82.49	1 212	0 08362
13	0		81 85	1 221	0 08696
	12		81 23	1 231	0 09031
14	0		80 60	1 240	0 09365
	12		79 98	1 250	0 09700
15	0		79 37	1 259	0 10034
	12		78 76	1 269	0 10369
16	0		78 16	1 279	0 10703
	12		77 56	1 289	0 11038
17	0		76 96	1 299	0 11372
	12		76 37	1 309	0 11707
18	0		75 79	1 319	0 12041
	12		75 20	1 329	0 12376
19	0		74 63	1 339	0 12710
	12		74 05	1 350	0 13045
20			73 49	1 360	0 13379
22			71 26	1 403	0 14717
24			69 10	1 447	0 16055
26			67 00	1 492	0 17393
28			64 97	1 539	0 18731
30			63 00	1 587	0 20069
32			61 08	1 637	0 21407
34			59 23	1 688	0 22745
36			57 43	1 741	0 24082
38			55 69	1 795	0 25420
40			54 00	1 851	0 26758
42			52 36	1 909	0 28096
44			50 78	1 969	0 29434
46			49 24	2 031	0 30772
48			47 74	2 094	0 32110
50			46 29	2 160	0 33448
52			44 89	2 227	0 34786
54			43 53	2 297	0 36124
56			42 21	2 369	0 37462
58			40 93	2 443	0 38799
60			39 69	2 519	0 40137
62			38 48	2 598	0 41475
64			37 31	2 679	0 42813
66			36 18	2 761	0 44151
68			35 08	2 850	0 45489
70			34 02	2 939	0 46827
72			32 99	3 031	0 48165
74			31 99	3 126	0 49503
76			31 02	3 224	0 50841
78			30 08	3 324	0 52179
80			29 16	3 429	0 53516
82			28 28	3 536	0 54854
84			27 42	3 646	0 56192
86			26 59	3 760	0 57530
88			25 78	3 878	0 58868
90			25 00	3 999	0 60206
92			24 24	4 125	0 61544
94			23 51	4 254	0 62882
96			22 79	4 387	0 64220
98			22 10	4 524	0 65558
100			21 43	4 666	0 66896
102			20 78	4 812	0 68233
104			20 15	4 962	0 69571
106			19 54	5 117	0 70909
108			18 95	5 278	0 72247
110			18 37	5 443	0 73585
112			17 81	5 614	0 74923
114			17 27	5 789	0 76261
116			16 75	5 970	0 77599
118			16 24	6 156	0 78937
120			15 75	6 349	0 80274
122			15 27	6 548	0 81612
124			14 81	6 753	0 82950
126			14 36	6 964	0 84288
128			13 92	7 182	0 85626
130			13 50	7 406	0 86964
132			13 09	7 635	0 88302
134			12 69	7 877	0 89640
136			12 31	8 124	0 90977
138			11 94	8 378	0 92315
140			11 57	8 640	0 93653
144			10 88	9 189	0 96329
148			10 23	9 773	0 99004
152			9 62	10 394	1 01681
156			9 05	11 055	1 04357
160			8 50		
164			8 00		
168			7 52		
172			7 07		
176			6 65		
180			6 25	16 000	1 20412
184			5 88	17 016	1 23088
188			5 53	18 098	1 25764
192			5 20	19 248	1 28439
196			4 88	20 471	1 31115
200			4 59	21 772	1 33791
210			3 94	25 398	1 40481
220			3 38	29 627	1 47170
230			2 89	34 561	1 53860
240			2 48	40 317	1 60549
250			2 13	47 031	1 67239
260			1 82	54 863	1 73928
270			1 56	63 999	1 80618
280			1 34	74 656	1 87307
290			1 15	87 083	1 93996
300			0 98	101 594	2 00687
320			0 72	138 247	2 14066
340			0 53	188 125	2 27445
360			0 39	255 996	2 40823
380			0 29	348 359	2 54203
400			0 21	474 045	2 67582

Cobalt-57

half life 270 d

t d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100 00	1 000	0 00000
10	97 47	1 026	0 01115
20	95 00	1 053	0 02230
30	92 59	1 080	0 03345
40	90 24	1 108	0 04460
50	87 95	1 137	0 05575
60	85 72	1 167	0 06690
70	83 55	1 197	0 07805
80	81 43	1 228	0 08919
90	79 37	1 260	0 10034
100	77 36	1 293	0 11149
110	75 40	1 326	0 12264
120	73 49	1 361	0 13379
130	71 62	1 396	0 14494
140	69 81	1 432	0 15609
150	68 04	1 470	0 16724
160	66 31	1 508	0 17839
170	64 63	1 547	0 18954
180	63 00	1 587	0 20069
190	61 40	1 629	0 21184
200	59 84	1 671	0 22299
210	58 33	1 714	0 23414
220	56 85	1 759	0 24528
230	55 41	1 805	0 25643
240	54 00	1 852	0 26758
250	52 63	1 900	0 27873
260	51 30	1 949	0 28988
270	50 00	2 000	0 30103
280	48 73	2 052	0 31218
290	47 50	2 105	0 32333
300	46 29	2 160	0 33449
320	43 98	2 274	0 35678
340	41 78	2 394	0 37908
360	39 68	2 520	0 40137
380	37 70	2 653	0 42367
400	35 81	2 792	0 44597
420	34 02	2 939	0 46827
440	32 32	3 094	0 49057
460	30 70	3 257	0 51287
480	29 16	3 429	0 53517
500	27 70	3 610	0 55747
540	25 00	4 000	0 60206
580	22 56	4 433	0 64666
620	20 36	4 912	0 69126
660	18 37	5 443	0 73585
700	16 58	6 032	0 78045
740	14 96	6 684	0 82505
780	13 50	7 407	0 86965
820	12.19	8 208	0 91424
860	10 99	9 096	0 95884
900	9 92	10 079	1 00344
950	8 73	11 460	1 05918
1000	7 67	13 030	1 11493
1050	6 75	14 814	1 17068
1100	5 94	16 843	1 22642
1150	5 22	19 150	1 28217
1200	4 59	21 773	1 33792
1250	4 04	24 755	1 39366
1300	3 55	28 146	1 44941
1350	3 12	32 000	1 50516
1400	2 75	36 383	1 56090
1450	2 42	41 367	1 61665
1500	2 13	47 032	1 67240
1600	1 64	60 798	1 78389
1700	1 27	78 593	1 89538

Cobalt-58

half life 71 d

t d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100 00	1 000	0 00000
1	99 03	1 010	0 00424
2	98 07	1 020	0 00848
3	97 11	1 030	0 01272
4	96 17	1 040	0 01696
5	95 24	1 050	0 02120
6	94 31	1 060	0 02544
7	93 39	1 071	0 02968
8	92 49	1 081	0 03392
9	91 59	1 092	0 03816
10	90 70	1 103	0 04240
11	89 82	1 113	0 04664
12	88 94	1 124	0 05088
13	88 08	1 135	0 05512
14	87 23	1 146	0 05936
15	86 38	1 158	0 06360
16	85 54	1 169	0 06784
17	84 71	1 181	0 07208
18	83 88	1 192	0 07632
19	83 07	1 204	0 08056
20	82 26	1 216	0 08480
21	81 46	1 228	0 08904
22	80 67	1 240	0 09328
23	79 89	1 252	0 09752
24	79 11	1,264	0 10176
25	78 34	1 276	0 10600
26	77 58	1 289	0 11024
27	76 83	1 302	0 11448
28	76 08	1 314	0 11872
29	75 34	1 327	0 12296
30	74 61	1 340	0 12720
31	73 89	1 353	0 13144
32	73 17	1 367	0 13568
33	72 46	1 380	0 13992
34	71 75	1 394	0 14416
35	71 06	1 407	0 14840
36	70 37	1 421	0 15264
37	69 68	1 435	0 15688
38	69 01	1 449	0 16112
39	68 34	1 463	0 16536
40	67 67	1 478	0 16960
41	67 01	1 492	0 17383
42	66 36	1 507	0 17807
43	65 72	1 522	0 18231
44	65 08	1 537	0 18655
45	64 45	1 552	0 19079
46	63 82	1 567	0 19503
47	63 20	1 582	0 19927
48	62 59	1 598	0 20351
49	61 98	1 613	0 20775
50	61 38	1 629	0 21199
52	60 19	1 661	0 22047
54	59 03	1 694	0 22895
56	57 89	1 728	0 23743
58	56 77	1 762	0 24591
60	55 67	1 796	0 25439
62	54 59	1 832	0 26287
64	53 54	1 868	0 27135
66	52 50	1 905	0 27983
68	51 49	1 942	0 28831
70	50 49	1 981	0 29679
72	49 51	2 020	0 30527
74	48 56	2 059	0 31375
76	47 62	2 100	0 32223
78	46 70	2 141	0 33071
80	45 79	2.184	0 33919
82	44 91	2 227	0 34767
84	44 04	2 271	0 35615
86	43 19	2 315	0 36463
88	42 35	2.361	0 37311
90	41 53	2 408	0 38159
92	40 73	2.455	0 39007
94	39 94	2 504	0 39855
96	39 17	2 553	0 40703
98	38 41	2 603	0 41551
100	37 67	2 655	0 42399
102	36 94	2 707	0 43247
104	36 23	2 760	0 44095
106	35 53	2 815	0 44943
108	34 84	2.870	0 45791
110	34 17	2 927	0 46639
112	33 51	2 984	0 47487
114	32 86	3 043	0 48335
116	32 22	3 103	0 49183
118	31 60	3 165	0 50031
120	30 99	3 227	0 50879
122	30 39	3 291	0 51726
124	29 80	3 355	0 52574
126	29 23	3 422	0 53422
128	28 66	3 489	0 54270
130	28 11	3 558	0 55118
132	27 56	3 628	0 55966
134	27 03	3 700	0 56814
136	26 51	3 772	0 57662
138	26 00	3 847	0 58510
140	25 49	3 923	0 59358
142	25 00	4 000	0 60206
144	24 52	4 079	0 61054
146	24 04	4 159	0 61902
148	23 58	4 241	0 62750
150	23 12	4 325	0 63598
152	22 67	4 410	0 64446
154	22 24	4 497	0 65294
156	21 81	4 586	0 66142
158	21 38	4 676	0,66990
160	20 97	4 768	0 67838
165	19,97	5 007	0 69958
170	19 02	5 257	0 72078
175	18 11	5 520	0 74198
180	17 25	5 797	0 76318
185	16 43	6 087	0 78438
190	15 65	6 391	0 80558
195	14 90	6 711	0 82678
200	14 19	7 047	0 84798
205	13 52	7 399	0 86917
210	12 87	7 769	0 89037
215	12 26	8 158	0 91157
220	11 67	8 566	0 93277
225	11 12	8 994	0 95397
230	10 59	9 444	0 97517
235	10 08	9 917	0 99637
240	9 60	10 413	1 01757
245	9 15	10 934	1 03877
250	8 71	11 481	1 05997
255	8 30	12 055	1 08117
260	7 90	12 658	1 10237
265	7 52	13 291	1 12357
270	7 17	13 956	1 14477
275	6 82	14 654	1 16597
280	6 50	15 387	1 18717
285	6 19	16 157	1 20836
290	5 89	16 965	1 22956
295	5 61	17 814	1 25076
300	5 35	18 705	1 27196
305	5 09	19 641	1 29316
310	4 85	20 623	1 31436
315	4 62	21 655	1 33556
320	4 40	22 738	1 35676
325	4 19	23 876	1 37796
330	3 99	25 070	1 39916
335	3 80	26 324	1 42036
340	3 62	27 641	1 44156
345	3 45	29 024	1 46276
350	3 28	30 476	1 48396
355	3 12	32 000	1 50516
360	2 98	33 601	1 52636
365	2 83	35 282	1 54755
370	2 70	37 047	1 56875
375	2 57	38 900	1 58995
380	2 45	40 846	1 61115
385	2 33	42 890	1 63235
390	2 22	45 035	1 65355
395	2 11	47 288	1 67475
400	2 01	49 654	1 69595
405	1 92	52 137	1 71715
410	1 83	54 746	1 73835
415	1 74	57 484	1 75955
420	1 66	60 360	1 78075
425	1 58	63 379	1 80195
430	1 50	66 550	1 82315
435	1 43	69 879	1 84435
440	1 36	73 375	1 86555
445	1 30	77 045	1 88674
450	1 24	80 899	1 90794
455	1 18	84 946	1 92914
460	1 12	89 196	1 95034
465	1 07	93 657	1 97154
470	1 02	98 343	1 99274
475	0 97	103 262	2 01394
480	0 92	108 428	2 03514
485	0 88	113 852	2 05634
490	0 84	119 547	2 07754
495	0 80	125 527	2 09874
500	0 76	131 807	2 11994
505	0 72	138 400	2 14114
510	0 69	145 324	2 16234
515	0 66	152 594	2 18354
520	0 62	160 227	2 20474
525	0 59	168 242	2 22594
530	0 57	176 658	2 24713
535	0 54	185 496	2 26833
540	0 51	194 775	2 28953
545	0 49	204 518	2 31073

Cobalt-60

half-life 5.26 y

t (d)	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.00000
20	99.28	1.007	0.00313
40	98.57	1.015	0.00627
60	97.86	1.022	0.00940
80	97.15	1.029	0.01254
100	96.46	1.037	0.01567
120	95.76	1.044	0.01880
140	95.07	1.052	0.02194
160	94.39	1.059	0.02507
180	93.71	1.067	0.02820
200	93.04	1.075	0.03134
220	92.37	1.083	0.03447
240	91.71	1.090	0.03761
260	91.05	1.098	0.04074
280	90.39	1.106	0.04387
300	89.74	1.114	0.04701
320	89.10	1.122	0.05014
340	88.46	1.131	0.05328
360	87.82	1.139	0.05641
380	87.19	1.147	0.05954
400	86.56	1.155	0.06268
420	85.94	1.164	0.06581
440	85.32	1.172	0.06894
460	84.71	1.181	0.07208
480	84.10	1.189	0.07521
500	83.49	1.198	0.07835
520	82.89	1.206	0.08148
540	82.30	1.215	0.08461
560	81.71	1.224	0.08775
580	81.12	1.233	0.09088
600	80.54	1.242	0.09401
620	79.96	1.251	0.09715
640	79.38	1.260	0.10028
660	78.81	1.269	0.10342
680	78.24	1.278	0.10655
700	77.68	1.287	0.10968
720	77.12	1.297	0.11282
740	76.57	1.306	0.11595
760	76.02	1.315	0.11909
780	75.47	1.325	0.12222
800	74.93	1.335	0.12535
820	74.39	1.344	0.12849
840	73.85	1.354	0.13162
860	73.32	1.364	0.13475
880	72.80	1.374	0.13789
900	72.27	1.384	0.14102
920	71.75	1.394	0.14416
940	71.24	1.404	0.14729
960	70.73	1.414	0.15042
980	70.22	1.424	0.15356
1000	69.71	1.434	0.15669
1020	69.21	1.445	0.15983
1040	68.71	1.455	0.16296
1060	68.22	1.466	0.16609
1080	67.73	1.476	0.16923
1100	67.24	1.487	0.17236
1120	66.76	1.498	0.17549
1140	66.28	1.509	0.17863
1160	65.80	1.520	0.18176
1180	65.33	1.531	0.18490
1200	64.86	1.542	0.18803
1250	63.70	1.570	0.19586
1300	62.56	1.598	0.20370
1350	61.44	1.628	0.21153
1400	60.34	1.657	0.21937
1450	59.26	1.687	0.22720
1500	58.21	1.718	0.23504
1550	57.16	1.749	0.24287
1600	56.14	1.781	0.25071
1650	55.14	1.814	0.25854
1700	54.15	1.847	0.26638
1750	53.19	1.880	0.27421
1800	52.23	1.914	0.28204
1850	51.30	1.949	0.28988
1900	50.38	1.985	0.29771
1950	49.48	2.021	0.30555
2000	48.60	2.058	0.31338
2050	47.73	2.095	0.32122
2100	46.88	2.133	0.32905
2150	46.04	2.172	0.33689
2200	45.21	2.212	0.34472
2250	44.41	2.252	0.35256
2300	43.61	2.293	0.36039
2350	42.83	2.335	0.36822
2400	42.07	2.377	0.37606
2450	41.31	2.420	0.38389
2500	40.58	2.464	0.39173
2550	39.85	2.509	0.39956
2600	39.14	2.555	0.40740
2650	38.44	2.602	0.41523
2700	37.75	2.649	0.42307
2750	37.08	2.697	0.43090
2800	36.41	2.746	0.43874
2850	35.76	2.796	0.44657
2900	35.12	2.847	0.45440
2950	34.50	2.899	0.46224
3000	33.88	2.952	0.47007
3050	33.27	3.005	0.47791
3100	32.68	3.060	0.48574
3150	32.09	3.116	0.49358
3200	31.52	3.173	0.50141
3250	30.96	3.230	0.50925
3300	30.40	3.289	0.51708
3350	29.86	3.349	0.52492
3400	29.33	3.410	0.53275
3450	28.80	3.472	0.54058
3500	28.29	3.535	0.54842
3550	27.78	3.600	0.55625
3600	27.28	3.665	0.56409
3650	26.80	3.732	0.57192
3700	26.32	3.800	0.57976
3750	25.85	3.869	0.58759
3800	25.38	3.939	0.59543
3850	24.93	4.011	0.60326
3900	24.49	4.084	0.61110
3950	24.05	4.158	0.61893
4000	23.62	4.234	0.62677
4050	23.20	4.311	0.63460
4100	22.78	4.390	0.64243
4150	22.37	4.470	0.65027
4200	21.97	4.551	0.65810
4250	21.58	4.634	0.66594
4300	21.19	4.718	0.67377
4350	20.82	4.804	0.68161
4400	20.44	4.891	0.68944
4450	20.08	4.981	0.69728
4500	19.72	5.071	0.70511
4550	19.37	5.164	0.71295
4600	19.02	5.258	0.72078
4650	18.68	5.353	0.72861
4700	18.35	5.451	0.73645
4750	18.02	5.550	0.74428
4800	17.70	5.651	0.75212
4850	17.38	5.754	0.75995
4900	17.07	5.859	0.76779
4950	16.76	5.965	0.77562
5000	16.46	6.074	0.78346
5050	16.17	6.184	0.79129
5100	15.88	6.297	0.79913
5150	15.60	6.412	0.80696
5200	15.32	6.528	0.81479
5250	15.04	6.647	0.82263
5300	14.78	6.768	0.83046
5350	14.51	6.891	0.83830
5400	14.25	7.017	0.84613
5450	14.00	7.144	0.85397
5500	13.75	7.274	0.86180
5550	13.50	7.407	0.86964
5600	13.26	7.542	0.87747
5650	13.02	7.679	0.88531
5700	12.79	7.819	0.89314
5750	12.56	7.961	0.90097
5800	12.34	8.106	0.90881
5850	12.12	8.254	0.91664
5900	11.90	8.404	0.92448
5950	11.69	8.557	0.93231
6000	11.48	8.713	0.94015
6050	11.27	8.871	0.94798
6100	11.07	9.033	0.95582
6150	10.87	9.197	0.96365
6200	10.68	9.365	0.97149
6250	10.49	9.535	0.97932
6300	10.30	9.709	0.98716
6350	10.12	9.885	0.99499
6400	9.94	10.065	1.00282
6450	9.76	10.248	1.01066
6500	9.58	10.435	1.01849
6550	9.41	10.625	1.02633
6600	9.24	10.818	1.03416
6650	9.08	11.015	1.04200
6700	8.92	11.216	1.04983
6750	8.76	11.420	1.05767
6800	8.60	11.628	1.06550
6850	8.45	11.840	1.07334
6900	8.30	12.055	1.08117
6950	8.15	12.275	1.08900
7000	8.00	12.498	1.09684
7050	7.86	12.725	1.10467
7100	7.72	12.957	1.11251
7150	7.58	13.193	1.12034
7200	7.44	13.433	1.12818
7250	7.31	13.678	1.13601
7300	7.18	13.927	1.14385
7350	7.05	14.180	1.15168
7400	6.93	14.438	1.15952
7450	6.80	14.701	1.16735
7500	6.68	14.969	1.17518
7550	6.56	15.241	1.18302
7600	6.44	15.519	1.19085
7650	6.33	15.801	1.19869
7700	6.22	16.089	1.20652
7750	6.10	16.382	1.21436
7800	6.00	16.680	1.22219
7850	5.89	16.983	1.23003
7900	5.78	17.293	1.23786
7950	5.68	17.607	1.24570
8000	5.58	17.928	1.25353
8050	5.48	18.254	1.26136
8100	5.38	18.587	1.26920
8150	5.28	18.925	1.27703
8200	5.19	19.269	1.28487
8250	5.10	19.620	1.29270
8300	5.01	19.977	1.30054
8350	4.92	20.341	1.30837
8400	4.83	20.711	1.31621
8450	4.74	21.088	1.32404
8500	4.66	21.472	1.33188
8550	4.57	21.863	1.33971
8600	4.49	22.261	1.34755
8650	4.41	22.666	1.35538
8700	4.33	23.079	1.36321
8750	4.26	23.499	1.37105
8800	4.18	23.927	1.37888
8850	4.10	24.362	1.38672
8900	4.03	24.806	1.39455
8950	3.96	25.257	1.40239
9000	3.89	25.717	1.41022
9050	3.82	26.185	1.41806
9100	3.75	26.662	1.42589
9150	3.68	27.147	1.43373
9200	3.62	27.641	1.44156
9250	3.55	28.145	1.44939
9300	3.49	28.657	1.45723
9350	3.43	29.179	1.46506
9400	3.37	29.710	1.47290
9450	3.31	30.251	1.48073
9500	3.25	30.801	1.48857
9550	3.19	31.362	1.49640
9600	3.13	31.933	1.50424
9650	3.08	32.514	1.51207
9700	3.02	33.106	1.51991
9750	2.97	33.709	1.52774
9800	2.91	34.322	1.53557
9850	2.86	34.947	1.54341
9900	2.81	35.583	1.55124
9950	2.76	36.231	1.55908
10000	2.71	36.890	1.56691
10050	2.66	37.562	1.57475
10100	2.61	38.246	1.58258
10150	2.57	38.942	1.59042
10200	2.52	39.651	1.59825
10250	2.48	40.373	1.60609
10300	2.43	41.107	1.61392
10350	2.39	41.856	1.62175
10400	2.35	42.618	1.62959
10450	2.30	43.393	1.63742
10500	2.26	44.183	1.64526
10550	2.22	44.988	1.65309
10600	2.18	45.807	1.66093
10650	2.14	46.640	1.66876
10700	2.11	47.489	1.67660
10750	2.07	48.354	1.68443
10800	2.03	49.234	1.69227
10850	1.99	50.130	1.70010
10900	1.96	51.043	1.70794
10950	1.92	51.972	1.71577
11000	1.89	52.918	1.72360
11050	1.86	53.881	1.73144
11100	1.82	54.862	1.73927
11150	1.79	55.861	1.74711
11200	1.76	56.878	1.75494
11250	1.73	57.913	1.76278
11300	1.70	58.967	1.77061
11350	1.67	60.041	1.77845
11400	1.64	61.134	1.78628
11450	1.61	62.247	1.79412
11500	1.58	63.380	1.80195
11550	1.55	64.533	1.80978
11600	1.52	65.708	1.81762
11650	1.49	66.904	1.82545
11700	1.47	68.122	1.83329
11750	1.44	69.362	1.84112
11800	1.42	70.625	1.84896
11850	1.39	71.910	1.85679
11900	1.37	73.219	1.86463
11950	1.34	74.552	1.87246
12000	1.32	75.909	1.88030
12050	1.29	77.291	1.88813
12100	1.27	78.698	1.89596
12150	1.25	80.131	1.90380
12200	1.23	81.589	1.91163
12250	1.20	83.075	1.91947
12300	1.18	84.587	1.92730
12350	1.16	86.127	1.93514
12400	1.14	87.694	1.94297
12450	1.12	89.291	1.95081
12500	1.10	90.916	1.95864
12550	1.08	92.571	1.96648
12600	1.06	94.256	1.97431
12650	1.04	95.972	1.98214
12700	1.02	97.719	1.98998
12750	1.01	99.498	1.99781
12800	0.99	101.309	2.00565
12850	0.97	103.153	2.01348
12900	0.95	105.031	2.02132
12950	0.94	106.943	2.02915
13000	0.92	108.890	2.03699
13050	0.90	110.872	2.04482
13100	0.89	112.890	2.05266
13150	0.87	114.945	2.06049
13200	0.85	117.037	2.06832
13250	0.84	119.168	2.07616
13300	0.82	121.337	2.08399
13350	0.81	123.546	2.09183
13400	0.79	125.795	2.09966
13450	0.78	128.085	2.10750
13500	0.77	130.416	2.11533
13550	0.75	132.790	2.12317
13600	0.74	135.208	2.13100
13650	0.73	137.669	2.13884
13700	0.71	140.175	2.14667
13750	0.70	142.727	2.15451
13800	0.69	145.325	2.16234
13850	0.68	147.970	2.17017
13900	0.66	150.664	2.17801
13950	0.65	153.406	2.18584
14000	0.64	156.199	2.19368
14050	0.63	159.042	2.20151
14100	0.62	161.937	2.20935
14150	0.61	164.885	2.21718
14200	0.60	167.887	2.22502
14250	0.58	170.943	2.23285
14300	0.57	174.055	2.24069
14350	0.56	177.223	2.24852
14400	0.55	180.449	2.25635
14450	0.54	183.734	2.26419
14500	0.53	187.078	2.27202
14550	0.52	190.484	2.27986
14600	0.52	193.951	2.28769
14650	0.51	197.482	2.29553
14700	0.50	201.077	2.30336

Copper-64

half-life 12.84 h

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
		0	100.00	1.000	0.00000
		20	98.22	1.018	0.00781
		40	96.47	1.037	0.01563
	1	0	94.74	1.055	0.02344
		20	93.06	1.075	0.03126
		40	91.40	1.094	0.03907
	2	0	89.77	1.114	0.04689
		20	88.16	1.134	0.05470
		40	86.59	1.155	0.06252
	3	0	85.05	1.176	0.07033
		20	83.53	1.197	0.07815
		40	82.04	1.219	0.08596
	4	0	80.58	1.241	0.09378
		20	79.14	1.264	0.10159
		40	77.73	1.286	0.10941
	5	0	76.34	1.310	0.11722
		20	74.98	1.334	0.12504
		40	73.65	1.358	0.13285
	6	0	72.33	1.383	0.14067
		20	71.04	1.408	0.14848
		40	69.78	1.433	0.15630
	7	0	68.53	1.459	0.16411
		20	67.31	1.486	0.17193
		40	66.11	1.513	0.17974
	8	0	64.93	1.540	0.18756
		20	63.77	1.568	0.19537
		40	62.63	1.597	0.20319
	9	0	61.52	1.626	0.21100
		20	60.42	1.655	0.21882
		40	59.34	1.685	0.22663
	10	0	58.28	1.716	0.23445
		20	57.24	1.747	0.24226
		40	56.22	1.779	0.25008
	11	0	55.22	1.811	0.25789
		20	54.24	1.844	0.26571
		40	53.27	1.877	0.27352
	12		52.32	1.911	0.28134
	13		49.57	2.017	0.30478
	14		46.96	2.129	0.32823
	15		44.50	2.247	0.35167
	16		42.16	2.372	0.37512
	17		39.94	2.504	0.39856
	18		37.84	2.642	0.42201
	19		35.85	2.789	0.44545
	20		33.97	2.944	0.46890
	21		32.19	3.107	0.49234
	22		30.49	3.279	0.51579
	23		28.89	3.461	0.53923
1	0		27.37	3.653	0.56268
	1		25.93	3.856	0.58612

t d	t h	t min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	2		24 57	4 070	0 60956
	3		23 28	4 295	0 63301
	4		22 06	4 534	0 65645
	5		20 90	4 785	0 67990
	6		19 80	5 051	0 70334
	7		18 76	5 331	0 72679
	8		17 77	5 626	0 75023
	9		16 84	5 937	0 77368
	10		15 95	6 268	0 79712
	11		15 12	6 616	0 82057
	12		14 32	6 983	0 84401
	15		12 18	8 210	0 91435
	18		10 36	9 653	0 98468
	21		8 81	11 351	1 05502
2	0		7 49	13 346	1 12535
	3		6 37	15 692	1 19568
	6		5 42	18 451	1 26602
	9		4 61	21 695	1 33635
	12		3 92	25 509	1 40669
	15		3 33	29 993	1 47702
	18		2 84	35 266	1 54736
	21		2 41	41 466	1 61769
3	0		2 05	48 756	1 68803
	3		1 74	57 327	1 75836
	6		1 48	67 405	1 82869
	9		1 26	79 255	1 89903
	12		1 07	93 189	1 96936
	15		0 91	109 571	2 03970
	18		0 78	128 834	2 11003
	21		0 66	151 484	2 18037
4	0		0 56	178 115	2 25070

Zinc-65

half life 245 d

d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100 00	1 000	0 00000
10	97 21	1 028	0 01229
20	94 50	1 058	0 02457
30	91 86	1 088	0 03686
40	89 30	1 119	0 04915
50	86 81	1 151	0 06144
60	84 39	1 185	0 07372
70	82 03	1 219	0 08601
80	79 75	1 253	0 09830
90	77 52	1 289	0 11058
100	75 36	1 326	0 12287
110	73 26	1 365	0 13516
120	71 21	1 404	0 14744
130	69 23	1 444	0 15973
140	67 30	1 485	0 17202
150	65 42	1 528	0 18430
160	63 59	1 572	0 19659
170	61 82	1 617	0 20888
180	60 09	1 664	0 22117
190	58 42	1 711	0 23345
200	56 79	1 760	0 24574
210	55 20	1 811	0 25803
220	53 66	1 863	0 27031
230	52 17	1 916	0 28260
240	50 71	1 971	0 29489
250	49 30	2 028	0 30717
260	47 92	2 086	0 31946
270	46 59	2 146	0 33175
280	45 29	2 208	0 34403
290	44 02	2 271	0 35632
300	42 79	2 336	0 36861
310	41 60	2 403	0 38090
320	40 44	2 472	0 39318
330	39 31	2 543	0 40547
340	38 22	2 616	0 41776
350	37 15	2 691	0 43004
360	36 11	2 769	0 44233
370	35 11	2 848	0 45462
380	34 13	2 930	0 46690
390	33 17	3 014	0 47919
400	32 25	3 100	0 49148
410	31 35	3 189	0 50376
420	30 48	3 281	0 51605
430	29 63	3 375	0 52834
440	28 80	3 472	0 54063
450	28 00	3 572	0 55291
460	27 21	3 674	0 56520
470	26 46	3 779	0 57749
480	25 72	3 888	0 58977
490	25 00	3 999	0 60206
500	24 30	4 114	0 61435
510	23 62	4 232	0 62663
520	22 97	4 354	0 63892
530	22 33	4 479	0 65121
540	21 70	4 607	0 66349
550	21 10	4 740	0 67578
560	20 51	4 876	0 68807
570	19 94	5 015	0 70035
580	19 38	5 159	0 71264
590	18 84	5 307	0 72493
600	18 31	5 460	0 73722
610	17 80	5 616	0 74950
620	17 31	5 778	0 76179
630	16 82	5 943	0 77408
640	16 35	6 114	0 78636
650	15 90	6 289	0 79865
660	15 45	6 470	0 81094
670	15 02	6 656	0 82322
680	14 60	6 847	0 83551
690	14 20	7 043	0 84780
700	13 80	7 245	0 86008
720	13 04	7 667	0 88466
740	12 32	8 113	0 90923
760	11 65	8 586	0 93380
780	11 01	9 085	0 95837
800	10 40	9 614	0 98295
820	9 83	10 174	1 00753
840	9 29	10 767	1 03210
860	8 78	11 394	1 05668
880	8 29	12 057	1 08125
900	7 84	12 759	1 10583
920	7 41	13 502	1 13040
940	7 00	14 288	1 15497
960	6 61	15 119	1 17955
980	6 25	16 000	1 20412
1000	5 91	16 931	1 22869
1040	5 27	18 960	1 27784
1080	4 71	21 231	1 32699
1120	4 21	23 775	1 37614
1160	3 76	26 624	1 42529
1200	3 35	29 814	1 47443
1240	3 00	33 387	1 52358
1280	2 67	37 387	1 57273
1320	2 39	41 867	1 62188
1360	2 13	46 883	1 67102
1400	1 90	52 501	1 72017
1500	1 44	69 668	1 84304
1600	1 08	92 448	1 96590
1700	0 82	122 681	2 08878
1800	0 61	162 797	2 21165
1900	0 46	216 034	2 33452

Selenium-75

half life 121 d

d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100 00	1 000	0 00000
4	97 73	1 023	0 00995
8	95 52	1 047	0 01990
12	93 36	1 071	0 02985
16	91 24	1 096	0 03981
20	89 17	1 121	0 04976
24	87 15	1 147	0 05971
28	85 18	1 174	0 06966
32	83 25	1 201	0 07961
36	81 36	1 229	0 08956
40	79 52	1 258	0 09951
44	77 72	1 287	0 10947
48	75 96	1 316	0 11942
52	74 24	1 347	0 12937
56	72 56	1 378	0 13932
60	70 91	1 410	0 14927
64	69 31	1 443	0 15922
68	67 74	1 476	0 16917
72	66 20	1 511	0 17913
76	64 70	1 546	0 18908
80	63 24	1 581	0 19903
84	61 80	1 618	0 20898
88	60 40	1 656	0 21893
92	59 04	1 694	0 22888
96	57 70	1 733	0 23883
100	56 39	1 773	0 24879
104	55 11	1 814	0 25874
108	53 87	1 856	0 26869
112	52 65	1 900	0 27864
116	51 45	1 944	0 28859
120	50 29	1 989	0 29854
124	49 15	2 035	0 30849
128	48 03	2 082	0 31845
132	46 95	2 130	0 32840
136	45 88	2 179	0 33835
140	44 84	2 230	0 34830
144	43 83	2 282	0 35825
148	42 83	2 335	0 36820
152	41 86	2 389	0 37815
156	40 92	2 444	0 38811
160	39 99	2 501	0 39806
170	37 76	2 648	0 42294
180	35 66	2 804	0 44782
190	33 67	2 970	0 47269
200	31 80	3 145	0 49757
210	30 03	3 330	0 52245
220	28 36	3 526	0 54733
230	26 78	3 734	0 57221
240	25 29	3 954	0 59709
250	23 88	4 188	0 62197
260	22 55	4 434	0 64684
270	21 29	4 696	0 67172
280	20 11	4 973	0 69660
290	18 99	5 266	0 72148
300	17 93	5 576	0 74636
310	16 93	5 905	0 77124
320	15 99	6 253	0 79612
330	15 10	6 622	0 82099
340	14 26	7 012	0 84587
350	13 47	7 426	0 87075
360	12 72	7 864	0 89563
370	12 01	8 327	0 92051
380	11 34	8 818	0 94539
390	10 71	9 338	0 97027
400	10 11	9 889	0 99514
410	9 55	10 472	1 02002
420	9 02	11 089	1 04490
430	8 52	11 743	1 06978
440	8 04	12 435	1 09466
450	7 59	13 169	1 11954
460	7 17	13 945	1 14442
470	6 77	14 767	1 16929
480	6 39	15 638	1 19417
490	6 04	16 560	1 21905
500	5 70	17 536	1 24393
510	5 39	18 570	1 26881
520	5 09	19 665	1 29369
530	4 80	20 824	1 31857
540	4 53	22 052	1 34345
550	4 28	23 352	1 36832
560	4 04	24 729	1 39320
570	3 82	26 187	1 41808
580	3 61	27 731	1 44296
590	3 41	29 366	1 46784
600	3 22	31 097	1 49272
610	3 04	32 930	1 51760
620	2 87	34 872	1 54247
630	2 71	36 928	1 56735
640	2 56	39 105	1 59223
650	2 41	41 410	1 61711
660	2 28	43 852	1 64199
670	2 15	46 437	1 66687
680	2 03	49 175	1 69175
690	1 92	52 074	1 71662
700	1 81	55 145	1 74150
710	1 71	58 396	1 76638
720	1 62	61 839	1 79126
730	1 53	65 485	1 81614
740	1 44	69 345	1 84102
750	1 36	73 434	1 86590
760	1 29	77 763	1 89077
770	1 21	82 348	1 91565
780	1 15	87 203	1 94053
790	1 08	92 344	1 96541
800	1 02	97 789	1 99029
810	0 97	103 554	2 01517
820	0 91	109 659	2 04005
830	0 86	116 125	2 06492
840	0 81	122 971	2 08980
850	0 77	130 221	2 11468
860	0 73	137 899	2 13956
870	0 68	146 029	2 16444
880	0 65	154 639	2 18932
890	0 61	163 756	2 21420
900	0 58	173 410	2 23908
910	0 54	183 634	2 26395
920	0 51	194 461	2 28883

Bromine-82

half life 35 4 h

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
		0	100 00	1 000	0 00000
		20	99 35	1 007	0 00283
		40	98 70	1 013	0 00567
	1	0	98 06	1 020	0 00850
		20	97 42	1 026	0 01134
		40	96 79	1 033	0 01417
	2	0	96 16	1 040	0 01701
		20	95 53	1 047	0 01984
		40	94 91	1 054	0 02268
	3	0	94 30	1 061	0 02551
		20	93 68	1 067	0 02835
		40	93 07	1 074	0 03118
	4	0	92 47	1 081	0 03401
		20	91 87	1 089	0 03685
		40	91 27	1 096	0 03968
	5	0	90 67	1 103	0 04252
		20	90 09	1 110	0 04535
		40	89 50	1 117	0 04819
	6	0	88 92	1 125	0 05102
		20	88 34	1 132	0 05386
		40	87 76	1 139	0 05669
	7	0	87 19	1 147	0 05953
		20	86 62	1 154	0 06236
		40	86 06	1 162	0 06520
	8	0	85 50	1 170	0 06803
		20	84 94	1 177	0 07086
		40	84 39	1 185	0 07370
	9	0	83 84	1 193	0 07653
		20	83 30	1 201	0 07937
		40	82 76	1 208	0 08220
	10	0	82 22	1 216	0 08504
		20	81 68	1 224	0 08787
		40	81 15	1 232	0 09071
	11	0	80 62	1 240	0 09354
		20	80 10	1 248	0 09638
		40	79 58	1 257	0 09921
	12	0	79 06	1 265	0 10204
		20	78 55	1 273	0 10488
		40	78 03	1 281	0 10771
	13	0	77 53	1 290	0 11055
		20	77 02	1 298	0 11338
		40	76 52	1 307	0 11622
	14	0	76 02	1 315	0 11905
		20	75 53	1 324	0 12189
		40	75 04	1 333	0 12472
	15	0	74 55	1 341	0 12756
		20	74 06	1 350	0 13039
		40	73 58	1 359	0 13322
	16	0	73 10	1 368	0 13606
		20	72 63	1 377	0 13889
		40	72 16	1 386	0 14173
	17	0	71 69	1 395	0 14456
		20	71 22	1 404	0 14740
		40	70 76	1 413	0 15023
	18	0	70 30	1 423	0 15307
		20	69 84	1 432	0 15590
		40	69 38	1 441	0 15874
	19	0	68 93	1 451	0 16157
		20	68 48	1 460	0 16440
		40	68 04	1,470	0 16724
	20	0	67 60	1 479	0 17007
		20	67 16	1 489	0 17291
		40	66 72	1 499	0 17574
	21	0	66 29	1 509	0 17858
		20	65 85	1 518	0 18141
		40	65 43	1 528	0 18425
	22	0	65 00	1 538	0 18708
		20	64 58	1 549	0 18992
		40	64 16	1 559	0 19275
	23	0	63 74	1 569	0 19559
		20	63 33	1 579	0 19842
		40	62 91	1 589	0 20125
1	0	0	62 50	1 600	0 20409
		20	62 10	1 610	0 20692
		40	61 69	1 621	0 20976
	1	0	61 29	1 632	0 21259
		20	60 89	1 642	0 21543
		40	60 50	1 653	0 21826
	2	0	60 10	1 664	0 22110
		20	59 71	1 675	0 22393
		40	59 32	1 686	0 22677
	3	0	58 94	1 697	0 22960
		20	58 56	1 708	0 23243
		40	58 17	1 719	0 23527
	4	0	57 80	1 730	0 23810
		20	57 42	1 742	0 24094
		40	57 05	1 753	0 24377
	5	0	56 68	1 764	0 24661
		20	56 31	1 776	0 24944
		40	55 94	1 788	0 25228
	6	0	55 58	1 799	0 25511
		20	55 21	1 811	0 25795
		40	54 86	1 823	0 26078
	7	0	54 50	1 835	0 26361
		20	54 14	1 847	0 26645
		40	53 79	1 859	0 26928
	8	0	53 44	1 871	0 27212
		20	53 09	1 883	0 27495
		40	52 75	1 896	0 27779
	9	0	52 41	1 908	0 28062
		20	52 06	1 921	0 28346
		40	51 73	1 933	0 28629
	10	0	51 39	1 946	0 28913
		20	51 06	1 959	0 29196
		40	50 72	1 971	0 29480
	11	0	50 39	1 984	0 29763
		20	50 07	1 997	0 30046
		40	49 74	2 010	0 30330
	12		49 42	2 024	0 30613
	13		48 46	2 064	0 31464
	14		47 52	2 104	0 32314
	15		46 60	2 146	0 33164
	16		45 69	2 189	0 34015
	17		44 81	2 232	0 34865
	18		43 94	2 276	0 35716
	19		43 09	2 321	0 36566
	20		42 25	2 367	0 37416
	21		41 43	2 414	0 38267
	22		40 63	2 461	0 39117

t d	t h	t min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
2	0		39.07	2.560	0.40818
	1		38.31	2.610	0.41668
	2		37.57	2.662	0.42519
	3		36.84	2.714	0.43369
	4		36.12	2.768	0.44219
	5		35.42	2.823	0.45070
	6		34.74	2.879	0.45920
	7		34.06	2.936	0.46770
	8		33.40	2.994	0.47621
	9		32.76	3.053	0.48471
	10		32.12	3.113	0.49321
	11		31.50	3.175	0.50172
	12		30.89	3.238	0.51022
	13		30.29	3.302	0.51873
	14		29.70	3.367	0.52723
	15		29.13	3.433	0.53573
	16		28.56	3.501	0.54424
	17		28.01	3.571	0.55274
	18		27.46	3.641	0.56124
	19		26.93	3.713	0.56975
	20		26.41	3.787	0.57825
	21		25.90	3.861	0.58676
	22		25.39	3.938	0.59526
	23		24.90	4.016	0.60376
3	0		24.42	4.095	0.61227
	1		23.95	4.176	0.62077
	2		23.48	4.259	0.62927
	3		23.03	4.343	0.63778
	4		22.58	4.429	0.64628
	5		22.14	4.516	0.65479
	6		21.71	4.606	0.66329
	7		21.29	4.697	0.67179
	8		20.88	4.790	0.68030
	9		20.47	4.884	0.68880
	10		20.08	4.981	0.69730
	11		19.69	5.079	0.70581
	12		19.31	5.180	0.71431
	13		18.93	5.282	0.72282
	14		18.56	5.387	0.73132
	15		18.20	5.493	0.73982
	16		17.85	5.602	0.74833
	17		17.51	5.713	0.75683
	18		17.17	5.826	0.76533
	19		16.83	5.941	0.77384
	20		16.51	6.058	0.78234
	21		16.19	6.178	0.79084
	22		15.87	6.300	0.79935
	23		15.56	6.425	0.80785
4	0		15.26	6.552	0.81636
	1		14.97	6.681	0.82486
	2		14.68	6.813	0.83336
	3		14.39	6.948	0.84187
	4		14.11	7.086	0.85037
	5		13.84	7.226	0.85887
	6		13.57	7.368	0.86738
	7		13.31	7.514	0.87588
	8		13.05	7.663	0.88439
	9		12.80	7.814	0.89289
	10		12.55	7.969	0.90139
	11		12.31	8.126	0.90990
	12		12.07	8.287	0.91840
	13		11.83	8.451	0.92690
	14		11.60	8.618	0.93541
	15		11.38	8.788	0.94391
	16		11.16	8.962	0.95242
	17		10.94	9.139	0.96092
	18		10.73	9.320	0.96942
	19		10.52	9.504	0.97793
	20		10.32	9.692	0.98643
	21		10.12	9.884	0.99493
	22		9.92	10.079	1.00344
	23		9.73	10.279	1.01194
5	0		9.54	10.482	1.02044
	6		8.48	11.789	1.07147
	12		7.54	13.258	1.12249
	18		6.71	14.911	1.17351
6	0		5.96	16.770	1.22453
	6		5.30	18.861	1.27556
	12		4.71	21.212	1.32658
	18		4.19	23.856	1.37760
7	0		3.73	26.830	1.42862
	6		3.31	30.175	1.47964
	12		2.95	33.937	1.53067
	18		2.62	38.167	1.58169
8	0		2.33	42.925	1.63271
	6		2.07	48.276	1.68373
	12		1.84	54.295	1.73476
	18		1.64	61.063	1.78578
9	0		1.46	68.675	1.83680
	6		1.29	77.237	1.88782
	12		1.15	86.865	1.93885
	18		1.02	97.694	1.98987
10	0		0.91	109.873	2.04089
	6		0.81	123.570	2.09191
	12		0.72	138.974	2.14293
	18		0.64	156.299	2.19396
11	0		0.57	175.784	2.24498
	6		0.51	197.697	2.29600
	12		0.45	222.343	2.34702

Krypton-85
half-life 10.6 y

t d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.00000
100	98.23	1.018	0.00778
200	96.48	1.036	0.01555
300	94.77	1.055	0.02333
400	93.09	1.074	0.03110
500	91.44	1.094	0.03888
600	89.81	1.113	0.04665
700	88.22	1.134	0.05443
800	86.66	1.154	0.06220
900	85.12	1.175	0.06998
1000	83.61	1.196	0.07775
1100	82.12	1.218	0.08553
1200	80.67	1.240	0.09331
1300	79.24	1.262	0.10108
1400	77.83	1.285	0.10886
1500	76.45	1.308	0.11663
1600	75.09	1.332	0.12441
1700	73.76	1.356	0.13218
1800	72.45	1.380	0.13996
1900	71.17	1.405	0.14773
2000	69.90	1.431	0.15551
2100	68.66	1.456	0.16328
2200	67.44	1.483	0.17106
2300	66.25	1.510	0.17884
2400	65.07	1.537	0.18661
2600	62.78	1.593	0.20216
2800	60.57	1.651	0.21771
3000	58.44	1.711	0.23326
3200	56.39	1.773	0.24881
3400	54.40	1.838	0.26436
3600	52.49	1.905	0.27992
3800	50.64	1.975	0.29547
4000	48.86	2.047	0.31102
4200	47.14	2.121	0.32657
4400	45.49	2.198	0.34212
4600	43.89	2.279	0.35767
4800	42.34	2.362	0.37322
5000	40.85	2.448	0.38877
5200	39.42	2.537	0.40432
5400	38.03	2.630	0.41987
5600	36.69	2.725	0.43542
5800	35.40	2.825	0.45098
6000	34.16	2.928	0.46653
6400	31.80	3.145	0.49763
6800	29.60	3.379	0.52873
7200	27.55	3.629	0.55983
7600	25.65	3.899	0.59093
8000	23.88	4.188	0.62203
8400	22.23	4.499	0.65314
8800	20.69	4.833	0.68424
9200	19.26	5.192	0.71534
9600	17.93	5.578	0.74644
10000	16.69	5.992	0.77754
10400	15.54	6.436	0.80865
10800	14.46	6.914	0.83975
11200	13.46	7.428	0.87085
11600	12.53	7.979	0.90195
12000	11.67	8.571	0.93305
13000	9.75	10.252	1.01081
14000	8.16	12.262	1.08856
15000	6.82	14.666	1.16632
16000	5.70	17.542	1.24407
17000	4.77	20.981	1.32182
18000	3.98	25.094	1.39958
19000	3.33	30.015	1.47733
20000	2.79	35.899	1.55509
21000	2.33	42.938	1.63284
22000	1.95	51.357	1.71060
23000	1.63	61.426	1.78835
24000	1.36	73.469	1.86610
25000	1.14	87.874	1.94386
26000	0.95	105.103	2.02161
27000	0.80	125.709	2.09937
28000	0.67	150.356	2.17712
29000	0.56	179.836	2.25488
30000	0.46	215.095	2.33263

Strontium-89
half-life 51 d

t d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.00000
1	98.65	1.014	0.00590
2	97.32	1.028	0.01181
3	96.00	1.042	0.01771
4	94.71	1.056	0.02361
5	93.43	1.070	0.02951
6	92.17	1.085	0.03542
7	90.92	1.100	0.04132
8	89.70	1.115	0.04722
9	88.49	1.130	0.05312
10	87.29	1.146	0.05903
12	84.95	1.177	0.07083
14	82.67	1.210	0.08264
16	80.46	1.243	0.09444
18	78.30	1.277	0.10625
20	76.20	1.312	0.11805
22	74.16	1.349	0.12986
24	72.17	1.386	0.14166
26	70.23	1.424	0.15347
28	68.35	1.463	0.16527
30	66.52	1.503	0.17708
32	64.73	1.545	0.18888
34	63.00	1.587	0.20069
36	61.31	1.631	0.21249
38	59.66	1.676	0.22430
40	58.06	1.722	0.23610
42	56.51	1.770	0.24791
44	54.99	1.818	0.25971
46	53.52	1.869	0.27152
48	52.08	1.920	0.28332
50	50.68	1.973	0.29513
52	49.32	2.027	0.30693
54	48.00	2.083	0.31874
56	46.71	2.141	0.33054
58	45.46	2.200	0.34235
60	44.24	2.260	0.35415
64	41.90	2.387	0.37776
68	39.68	2.520	0.40137
72	37.59	2.661	0.42499
76	35.60	2.809	0.44860
80	33.71	2.966	0.47221
84	31.93	3.132	0.49582
88	30.24	3.307	0.51943
92	28.64	3.492	0.54304
96	27.12	3.687	0.56665
100	25.69	3.893	0.59026
104	24.33	4.110	0.61387
108	23.04	4.340	0.63748
112	21.82	4.582	0.66109
116	20.67	4.838	0.68470
120	19.57	5.109	0.70831
124	18.54	5.394	0.73192
128	17.56	5.695	0.75553
132	16.63	6.014	0.77914
136	15.75	6.350	0.80275
140	14.92	6.704	0.82636
150	13.02	7.680	0.88539
160	11.37	8.799	0.94441
170	9.92	10.079	1.00344
180	8.66	11.547	1.06246
190	7.56	13.228	1.12149
200	6.60	15.154	1.18051
210	5.76	17.360	1.23954
220	5.03	19.887	1.29857
230	4.39	22.782	1.35759
240	3.83	26.099	1.41662
250	3.34	29.898	1.47564
260	2.92	34.251	1.53467
270	2.55	39.237	1.59369
280	2.22	44.949	1.65272
290	1.94	51.493	1.71175
300	1.70	58.989	1.77077
310	1.48	67.577	1.82980
320	1.29	77.415	1.88882
330	1.13	88.685	1.94785
340	0.98	101.596	2.00687
350	0.86	116.386	2.06590
360	0.75	133.329	2.12493
370	0.65	152.740	2.18395
380	0.57	174.976	2.24298
390	0.50	200.449	2.30200

Strontium-90
half-life 28 y

t d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.00000
100	99.32	1.007	0.00294
200	98.65	1.014	0.00589
300	97.99	1.021	0.00883
400	97.33	1.027	0.01177
500	96.67	1.034	0.01472
600	96.01	1.042	0.01766
700	95.37	1.049	0.02060
800	94.72	1.056	0.02355
900	94.08	1.063	0.02649
1000	93.45	1.070	0.02944
1100	92.82	1.077	0.03238
1200	92.19	1.085	0.03532
1300	91.57	1.092	0.03827
1400	90.95	1.100	0.04121
1500	90.33	1.107	0.04415
1600	89.72	1.115	0.04710
1700	89.12	1.122	0.05004
1800	88.51	1.130	0.05298
1900	87.92	1.137	0.05593
2000	87.32	1.145	0.05887
2200	86.15	1.161	0.06476
2400	84.99	1.177	0.07065
2600	83.84	1.193	0.07653
2800	82.71	1.209	0.08242
3000	81.60	1.225	0.08831
3200	80.50	1.242	0.09419
3400	79.42	1.259	0.10008
3600	78.35	1.276	0.10597
3800	77.29	1.294	0.11186
4000	76.25	1.311	0.11774
4200	75.23	1.329	0.12363
4400	74.21	1.347	0.12952
4600	73.21	1.366	0.13540
4800	72.23	1.384	0.14129
5000	71.26	1.403	0.14718
5200	70.30	1.423	0.15307
5400	69.35	1.442	0.15895
5600	68.42	1.462	0.16484
5800	67.50	1.482	0.17073
6000	66.59	1.502	0.17661
6200	65.69	1.522	0.18250
6400	64.81	1.543	0.18839
6600	63.93	1.564	0.19427
6800	63.07	1.585	0.20016
7000	62.22	1.607	0.20605
7200	61.39	1.629	0.21194
7400	60.56	1.651	0.21782
7600	59.74	1.674	0.22371
7800	58.94	1.697	0.22960
8000	58.15	1.720	0.23548
8200	57.36	1.743	0.24137
8400	56.59	1.767	0.24726
8600	55.83	1.791	0.25315
8800	55.08	1.816	0.25903
9000	54.34	1.840	0.26492
9200	53.60	1.866	0.27081
9400	52.88	1.891	0.27669
9600	52.17	1.917	0.28258
9800	51.47	1.943	0.28847
10000	50.77	1.969	0.29436
10200	50.09	1.996	0.30024
10400	49.42	2.024	0.30613
10600	48.75	2.051	0.31202
10800	48.09	2.079	0.31790
11000	47.45	2.108	0.32379
11200	46.81	2.136	0.32968
11400	46.18	2.166	0.33557
11600	45.56	2.195	0.34145
11800	44.94	2.225	0.34734
12000	44.34	2.255	0.35323
12200	43.74	2.286	0.35911
12400	43.15	2.317	0.36500
12600	42.57	2.349	0.37089
12800	42.00	2.381	0.37678
13000	41.43	2.414	0.38266
13200	40.87	2.447	0.38855
13400	40.32	2.480	0.39444
13600	39.78	2.514	0.40032
13800	39.25	2.548	0.40621
14000	38.72	2.583	0.41210
14200	38.20	2.618	0.41799
14400	37.68	2.654	0.42387
14600	37.17	2.690	0.42976
14800	36.67	2.727	0.43565
15000	36.18	2.764	0.44153
15200	35.69	2.802	0.44742
15400	35.21	2.840	0.45331
15600	34.74	2.879	0.45919
15800	34.27	2.918	0.46508
16000	33.81	2.958	0.47097
16500	32.68	3.060	0.48569
17000	31.59	3.165	0.50040
17500	30.54	3.274	0.51512
18000	29.52	3.387	0.52984
18500	28.54	3.504	0.54456
19000	27.59	3.625	0.55928
19500	26.67	3.750	0.57399
20000	25.78	3.879	0.58871
20500	24.92	4.013	0.60343
21000	24.09	4.151	0.61815
21500	23.29	4.294	0.63286
22000	22.51	4.442	0.64758
22500	21.76	4.595	0.66230
23000	21.04	4.754	0.67702
23500	20.34	4.917	0.69174
24000	19.66	5.087	0.70645
24500	19.00	5.262	0.72117
25000	18.37	5.444	0.73589
25500	17.76	5.631	0.75061
26000	17.17	5.825	0.76532
26500	16.59	6.026	0.78004
27000	16.04	6.234	0.79476
27500	15.51	6.449	0.80948
28000	14.99	6.671	0.82420
28500	14.49	6.901	0.83891
29000	14.01	7.139	0.85363
29500	13.54	7.385	0.86835

t (d)	N_t	N_0/N_t	$\log_{10} N_0/N_t$
30000	13.09	7.640	0.88307
30500	12.65	7.903	0.89779
31000	12.23	8.175	0.91250
31500	11.82	8.457	0.92722
32000	11.43	8.749	0.94194
32500	11.05	9.050	0.95666
33000	10.68	9.362	0.97137
33500	10.33	9.695	0.98609
34000	9.98	10.019	1.00081
34500	9.65	10.364	1.01553
35000	9.33	10.721	1.03025
35500	9.02	11.091	1.04496
36000	8.72	11.473	1.05968
36500	8.43	11.869	1.07440
37000	8.14	12.278	1.08912
37500	7.87	12.701	1.10383
38000	7.61	13.139	1.11855
38500	7.36	13.592	1.13327
39000	7.11	14.060	1.14799
39500	6.88	14.545	1.16271
40000	6.65	15.046	1.17742
40500	6.42	15.565	1.19214
41000	6.21	16.101	1.20686
41500	6.00	16.656	1.22158
42000	5.80	17.230	1.23629
42500	5.61	17.824	1.25101
43000	5.42	18.439	1.26573
43500	5.24	19.074	1.28045
44000	5.07	19.732	1.29517
44500	4.90	20.412	1.30988
45000	4.74	21.115	1.32460
45500	4.58	21.843	1.33932
46000	4.43	22.596	1.35404
46500	4.28	23.375	1.36875
47000	4.14	24.181	1.38347
47500	4.00	25.014	1.39819
48000	3.86	25.877	1.41291
48500	3.74	26.769	1.42763
49000	3.61	27.691	1.44234
49500	3.49	28.646	1.45706
50000	3.37	29.633	1.47178
50500	3.26	30.655	1.48650
51000	3.15	31.711	1.50121
51500	3.05	32.804	1.51593
52000	2.95	33.935	1.53065
52500	2.85	35.105	1.54537
53000	2.75	36.315	1.56009
53500	2.66	37.567	1.57480
54000	2.57	38.862	1.58952
54500	2.49	40.201	1.60424
55000	2.40	41.587	1.61896
55500	2.32	43.020	1.63367
56000	2.25	44.503	1.64839
56500	2.17	46.037	1.66311
57000	2.10	47.624	1.67783
57500	2.03	49.266	1.69255
58000	1.96	50.964	1.70726
58500	1.90	52.721	1.72198
59000	1.83	54.538	1.73670
59500	1.77	56.418	1.75142
60000	1.71	58.363	1.76613
60500	1.66	60.374	1.78085
61000	1.60	62.455	1.79557
61500	1.55	64.608	1.81029
62000	1.50	66.835	1.82501
62500	1.45	69.139	1.83972
63000	1.40	71.522	1.85444
63500	1.35	73.988	1.86916
64000	1.31	76.538	1.88388
64500	1.26	79.176	1.89859
65000	1.22	81.905	1.91331
65500	1.18	84.729	1.92803
66000	1.14	87.649	1.94275
66500	1.10	90.670	1.95747
67000	1.07	93.796	1.97218
67500	1.03	97.029	1.98690
68000	1.00	100.374	2.00162
68500	0.96	103.833	2.01634
69000	0.93	107.413	2.03105
69500	0.90	111.115	2.04577
70000	0.87	114.945	2.06049
70500	0.84	118.907	2.07521
71000	0.81	123.006	2.08993
71500	0.79	127.246	2.10464
72000	0.76	131.632	2.11936
72500	0.73	136.169	2.13408
73000	0.71	140.863	2.14880
73500	0.69	145.718	2.16352
74000	0.66	150.741	2.17823
74500	0.64	155.938	2.19295
75000	0.62	161.313	2.20767
75500	0.60	166.873	2.22239
76000	0.58	172.625	2.23710
76500	0.56	178.575	2.25182
77000	0.54	184.731	2.26654
77500	0.52	191.098	2.28126
78000	0.51	197.686	2.29598
78500	0.49	204.500	2.31069

Yttrium-90
half-life 64.2 h

t d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100.00	1.000	0.00000
	1		98.93	1.011	0.00469
	2		97.86	1.022	0.00938
	3		96.81	1.033	0.01407
	4		95.77	1.044	0.01876
	5		94.74	1.055	0.02344
	6		93.73	1.067	0.02813
	7		92.72	1.079	0.03282
	8		91.73	1.090	0.03751
	9		90.74	1.102	0.04220
	10		89.77	1.114	0.04689
	11		88.80	1.126	0.05158
	12		87.85	1.138	0.05627
	13		86.90	1.151	0.06096
	14		85.97	1.163	0.06565
	15		85.05	1.176	0.07033
	16		84.13	1.189	0.07502
	17		83.23	1.201	0.07971
	18		82.34	1.215	0.08440
	19		81.45	1.228	0.08909
	20		80.58	1.241	0.09378
	21		79.71	1.254	0.09847
	22		78.86	1.268	0.10316
	23		78.01	1.282	0.10785
1	0		77.17	1.296	0.11254
	1		76.34	1.310	0.11722
	2		75.52	1.324	0.12191
	3		74.71	1.339	0.12660
	4		73.91	1.353	0.13129
	5		73.12	1.368	0.13598
	6		72.33	1.383	0.14067
	7		71.56	1.398	0.14536
	8		70.79	1.413	0.15005
	9		70.03	1.428	0.15474
	10		69.27	1.444	0.15942
	11		68.53	1.459	0.16411
	12		67.79	1.475	0.16880
	13		67.07	1.491	0.17349
	14		66.35	1.507	0.17818
	15		65.63	1.524	0.18287
	16		64.93	1.540	0.18756
	17		64.23	1.557	0.19225
	18		63.54	1.574	0.19694
	19		62.86	1.591	0.20163
	20		62.19	1.608	0.20631
	21		61.52	1.626	0.21100
	22		60.86	1.643	0.21569
	23		60.20	1.661	0.22038
2	0		59.56	1.679	0.22507
	1		58.92	1.697	0.22976
	2		58.28	1.716	0.23445
	3		57.66	1.734	0.23914
	4		57.04	1.753	0.24383
	5		56.43	1.772	0.24851
	6		55.82	1.791	0.25320
	7		55.22	1.811	0.25789
	8		54.63	1.831	0.26258
	9		54.04	1.850	0.26727
	10		53.46	1.871	0.27196
	11		52.89	1.891	0.27665
	12		52.32	1.911	0.28134
	13		51.76	1.932	0.28603
	14		51.20	1.953	0.29072
	15		50.65	1.974	0.29540
	16		50.11	1.996	0.30009
	17		49.57	2.017	0.30478
	18		49.04	2.039	0.30947
	19		48.51	2.061	0.31416
	20		47.99	2.084	0.31885
	21		47.47	2.106	0.32354
	22		46.96	2.129	0.32823
	23		46.46	2.152	0.33292
3	0		45.96	2.176	0.33761
	1		45.47	2.199	0.34229
	2		44.98	2.223	0.34698
	3		44.50	2.247	0.35167
	4		44.02	2.272	0.35636
	5		43.55	2.296	0.36105
	6		43.08	2.321	0.36574
	7		42.62	2.347	0.37043
	8		42.16	2.372	0.37512
	9		41.71	2.398	0.37981
	10		41.26	2.424	0.38449
	11		40.81	2.450	0.38918
	12		40.38	2.477	0.39387
	13		39.94	2.504	0.39856
	14		39.51	2.531	0.40325
	15		39.09	2.558	0.40794
	16		38.67	2.586	0.41263
	17		38.25	2.614	0.41732
	18		37.84	2.642	0.42201
	19		37.44	2.671	0.42670
	20		37.04	2.700	0.43138
	21		36.64	2.729	0.43607
	22		36.24	2.759	0.44076
	23		35.85	2.789	0.44545
4	0		35.47	2.819	0.45014
	1		35.09	2.850	0.45483
	2		34.71	2.881	0.45952
	3		34.34	2.912	0.46421
	4		33.97	2.944	0.46890
	5		33.61	2.976	0.47358
	6		33.24	3.008	0.47827
	7		32.89	3.041	0.48296
	8		32.53	3.074	0.48765
	9		32.19	3.107	0.49234
	10		31.84	3.141	0.49703
	11		31.50	3.175	0.50172
	12		31.16	3.209	0.50641
	13		30.83	3.244	0.51110
	14		30.49	3.279	0.51579
	15		30.17	3.315	0.52047
	16		29.84	3.351	0.52516
	17		29.52	3.387	0.52985
	18		29.21	3.424	0.53454
	19		28.89	3.461	0.53923
	20		28.58	3.499	0.54392
	21		28.27	3.537	0.54861
	22		27.97	3.575	0.55330
	23		27.67	3.614	0.55799
5	0		27.37	3.653	0.56268
	1		27.08	3.693	0.56736
	2		26.79	3.733	0.57205
	3		26.50	3.773	0.57674
	4		26.22	3.814	0.58143
	5		25.93	3.856	0.58612
	6		25.66	3.898	0.59081
	7		25.38	3.940	0.59550
	8		25.11	3.983	0.60019
	9		24.84	4.026	0.60488
	10		24.57	4.070	0.60956
	11		24.31	4.114	0.61425
	12		24.05	4.159	0.61894
	13		23.79	4.204	0.62363
	14		23.53	4.249	0.62832
	15		23.28	4.295	0.63301
	16		23.03	4.342	0.63770
	17		22.78	4.389	0.64239
	18		22.54	4.437	0.64708
	19		22.30	4.485	0.65177
	20		22.06	4.534	0.65645
	21		21.82	4.583	0.66114
	22		21.59	4.633	0.66583
	23		21.35	4.683	0.67052
6	0		21.12	4.734	0.67521
	1		20.90	4.785	0.67990
	2		20.67	4.837	0.68459
	3		20.45	4.890	0.68928
	4		20.23	4.943	0.69397
	5		20.01	4.996	0.69865
	6		19.80	5.051	0.70334
	7		19.59	5.105	0.70803
	8		19.38	5.161	0.71272
	9		19.17	5.217	0.71741
	10		18.96	5.274	0.72210
	11		18.76	5.331	0.72679
	12		18.56	5.389	0.73148
	13		18.36	5.447	0.73617
	14		18.16	5.506	0.74086
	15		17.97	5.566	0.74554
	16		17.77	5.626	0.75023
	17		17.58	5.688	0.75492
	18		17.39	5.749	0.75961
	19		17.21	5.812	0.76430
	20		17.02	5.875	0.76899
	21		16.84	5.939	0.77368
	23		16.66	6.003	0.77837
	23		16.48	6.068	0.78306
7	0		16.30	6.134	0.78775
	6		15.28	6.545	0.81588
	12		14.32	6.983	0.84401
	18		13.42	7.450	0.87215
8	0		12.58	7.948	0.90028
	6		11.79	8.480	0.92841
	12		11.05	9.048	0.95655
	18		10.36	9.653	0.98468
9	0		9.71	10.299	1.01282
	6		9.10	10.989	1.04095
	12		8.53	11.724	1.06908
	18		7.99	12.509	1.09722
10	0		7.49	13.346	1.12535
	12		6.58	15.192	1.18162
11	0		5.78	17.294	1.23789
	12		5.08	19.686	1.29415
12	0		4.46	22.409	1.35042
	12		3.92	25.509	1.40669
13	0		3.44	29.037	1.46296
	12		3.03	33.054	1.51922
14	0		2.66	37.626	1.57549
	12		2.33	42.831	1.63176
15	0		2.05	48.756	1.68803
	12		1.80	55.500	1.74429
16	0		1.59	63.177	1.80056
	12		1.39	71.916	1.85683
17	0		1.22	81.864	1.91310
	12		1.07	93.189	1.96936
18	0		0.94	106.079	2.02563
	12		0.83	120.753	2.08190
19	0		0.73	137.457	2.13817
	12		0.64	156.471	2.19443
20	0		0.56	178.115	2.25070
	12		0.49	202.753	2.30697

Molybdenum-99
half life 67 h

t d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100.00	1.000	0.00000
	1		98.97	1.010	0.00449
	2		97.95	1.021	0.00899
	3		96.94	1.032	0.01348
	4		95.95	1.042	0.01797
	5		94.96	1.053	0.02246
	6		93.98	1.064	0.02696
	7		93.01	1.075	0.03145
	8		92.06	1.086	0.03594
	9		91.11	1.098	0.04044
	10		90.17	1.109	0.04493
	11		89.24	1.121	0.04942
	12		88.33	1.132	0.05392
	13		87.42	1.144	0.05841
	14		86.52	1.156	0.06290
	15		85.63	1.168	0.06740
	16		84.74	1.180	0.07189
	17		83.87	1.192	0.07638
	18		83.01	1.205	0.08087
	19		82.15	1.217	0.08537
	20		81.31	1.230	0.08986
	21		80.47	1.243	0.09435
	22		79.64	1.256	0.09885
	23		78.82	1.269	0.10334
1	0		78.01	1.282	0.10783
	1		77.21	1.295	0.11233
	2		76.42	1.309	0.11682
	3		75.63	1.322	0.12131
	4		74.85	1.336	0.12580
	5		74.08	1.350	0.13030
	6		73.32	1.364	0.13479
	7		72.56	1.378	0.13928
	8		71.82	1.392	0.14378
	9		71.08	1.407	0.14827
	10		70.35	1.422	0.15276
	11		69.62	1.436	0.15726
	12		68.91	1.451	0.16175
	13		68.20	1.466	0.16624
	14		67.49	1.482	0.17073
	15		66.80	1.497	0.17523
	16		66.11	1.513	0.17972
	17		65.43	1.528	0.18421
	18		64.76	1.544	0.18871
	19		64.09	1.560	0.19320
	20		63.43	1.576	0.19769
	21		62.78	1.593	0.20219
	22		62.13	1.609	0.20668
	23		61.49	1.626	0.21117
2	0		60.86	1.643	0.21566
	1		60.23	1.660	0.22016
	2		59.61	1.677	0.22465
	3		59.00	1.695	0.22914
	4		58.39	1.713	0.23364
	5		57.79	1.730	0.23813
	6		57.20	1.748	0.24262
	7		56.61	1.767	0.24712
	8		56.03	1.785	0.25161
	9		55.45	1.803	0.25610
	10		54.88	1.822	0.26059
	11		54.31	1.841	0.26509
	12		53.76	1.860	0.26958
	13		53.20	1.880	0.27407
	14		52.65	1.899	0.27857
	15		52.11	1.919	0.28306
	16		51.58	1.939	0.28755
	17		51.05	1.959	0.29205
	18		50.52	1.979	0.29654
	19		50.00	2.000	0.30103
	20		49.49	2.021	0.30552
	21		48.98	2.042	0.31002
	22		48.47	2.063	0.31451
	23		47.97	2.085	0.31900
3	0		47.48	2.106	0.32350
	1		46.99	2.128	0.32799
	2		46.51	2.150	0.33248
	3		46.03	2.173	0.33698
	4		45.55	2.195	0.34147
	5		45.09	2.218	0.34596
	6		44.62	2.241	0.35045
	7		44.16	2.264	0.35495
	8		43.71	2.288	0.35944
	9		43.26	2.312	0.36393
	10		42.81	2.336	0.36843
	11		42.37	2.360	0.37292
	12		41.94	2.385	0.37741
	13		41.50	2.409	0.38191

t: d	t: h	t: min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	14		41.08	2.434	0.38640
	15		40.65	2.460	0.39089
	16		40.24	2.485	0.39538
	17		39.82	2.511	0.39988
	18		39.41	2.537	0.40437
	19		39.01	2.564	0.40886
	20		38.61	2.590	0.41336
	21		38.21	2.617	0.41785
	22		37.81	2.644	0.42234
	23		37.43	2.672	0.42684
4	0		37.04	2.700	0.43133
	1		36.66	2.728	0.43582
	2		36.28	2.756	0.44031
	3		35.91	2.785	0.44481
	4		35.54	2.814	0.44930
	5		35.17	2.843	0.45379
	6		34.81	2.873	0.45829
	7		34.45	2.903	0.46278
	8		34.10	2.933	0.46727
	9		33.75	2.963	0.47177
	10		33.40	2.994	0.47626
	11		33.06	3.025	0.48075
	12		32.72	3.057	0.48524
	13		32.38	3.088	0.48974
	14		32.05	3.121	0.49423
	15		31.72	3.153	0.49872
	16		31.39	3.186	0.50322
	17		31.07	3.219	0.50771
	18		30.75	3.252	0.51220
	19		30.43	3.286	0.51670
	20		30.12	3.320	0.52119
	21		29.81	3.355	0.52568
	22		29.50	3.390	0.53017
	23		29.20	3.425	0.53467
5	0		28.90	3.461	0.53916
	1		28.60	3.497	0.54365
	2		28.30	3.533	0.54815
	3		28.01	3.570	0.55264
	4		27.72	3.607	0.55713
	5		27.44	3.644	0.56163
	6		27.16	3.682	0.56612
	7		26.88	3.721	0.57061
	8		26.60	3.759	0.57510
	9		26.33	3.798	0.57960
	10		26.06	3.838	0.58409
	11		25.79	3.878	0.58858
	12		25.52	3.918	0.59308
	13		25.26	3.959	0.59757
	14		25.00	4.000	0.60206
	15		24.74	4.042	0.60656
	16		24.49	4.084	0.61105
	17		24.24	4.126	0.61554
	18		23.99	4.169	0.62003
	19		23.74	4.212	0.62453
	20		23.50	4.256	0.62902
	21		23.25	4.300	0.63351
	22		23.01	4.345	0.63801
	23		22.78	4.390	0.64250
6	0		22.54	4.436	0.64699
	1		22.31	4.482	0.65149
	2		22.08	4.529	0.65598
	3		21.85	4.576	0.66047
	4		21.63	4.623	0.66496
	5		21.41	4.672	0.66946
	6		21.19	4.720	0.67395
	7		20.97	4.769	0.67844
	8		20.75	4.819	0.68294
	9		20.54	4.869	0.68743
	10		20.33	4.920	0.69192
	11		20.12	4.971	0.69642
	12		19.91	5.022	0.70091
	13		19.71	5.075	0.70540
	14		19.50	5.127	0.70989
	15		19.30	5.181	0.71439
	16		19.10	5.235	0.71888
	17		18.91	5.289	0.72337
	18		18.71	5.344	0.72787
	19		18.52	5.400	0.73236
	20		18.33	5.456	0.73685
	21		18.14	5.512	0.74135
	22		17.95	5.570	0.74584
	23		17.77	5.628	0.75033
7	0		17.59	5.686	0.75482
	6		16.53	6.050	0.78178
	12		15.53	6.438	0.80874
	18		14.60	6.850	0.83570
8	0		13.72	7.289	0.86266
	6		12.89	7.756	0.88961
	12		12.12	8.252	0.91657
	18		11.39	8.781	0.94353
9	0		10.70	9.343	0.97049
	6		10.06	9.941	0.99745
	12		9.45	10.578	1.02440
	18		8.88	11.255	1.05136
10	0		8.35	11.976	1.07832
	12		7.38	13.559	1.13224
11	0		6.51	15.352	1.18615
	12		5.75	17.381	1.24007
12	0		5.08	19.678	1.29398
	12		4.49	22.279	1.34790

t: d	t: h	t: min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
13	0		3.96	25.224	1.40182
	12		3.50	28.558	1.45573
14	0		3.09	32.333	1.50965
	12		2.73	36.607	1.56357
15	0		2.41	41.446	1.61748
	12		2.13	46.924	1.67140
16	0		1.88	53.127	1.72531
	12		1.66	60.149	1.77923
17	0		1.47	68.100	1.83315
	12		1.30	77.101	1.88706
18	0		1.15	87.293	1.94098
	12		1.01	98.831	1.99489
19	0		0.89	111.895	2.04881
	12		0.79	126.685	2.10273
20	0		0.70	143.431	2.15664
	12		0.62	162.389	2.21056
21	0		0.54	183.854	2.26447
	12		0.48	208.156	2.31839

Technetium-99m

half-life 6 h

t: d	t: h	t: min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
		0	100.00	1.000	0.00000
		5	99.04	1.010	0.00418
		10	98.09	1.019	0.00836
		15	97.15	1.029	0.01254
		20	96.22	1.039	0.01672
		25	95.30	1.049	0.02090
		30	94.39	1.059	0.02509
		35	93.48	1.070	0.02927
		40	92.59	1.080	0.03345
		45	91.70	1.091	0.03763
		50	90.82	1.101	0.04181
		55	89.95	1.112	0.04599
	1	0	89.09	1.122	0.05017
		5	88.24	1.133	0.05435
		10	87.39	1.144	0.05853
		15	86.55	1.155	0.06271
		20	85.72	1.167	0.06690
		25	84.90	1.178	0.07108
		30	84.09	1.189	0.07526
		35	83.28	1.201	0.07944
		40	82.49	1.212	0.08362
		45	81.70	1.224	0.08780
		50	80.91	1.236	0.09198
		55	80.14	1.248	0.09616
	2	0	79.37	1.260	0.10034
		5	78.61	1.272	0.10452
		10	77.86	1.284	0.10871
		15	77.11	1.297	0.11289
		20	76.37	1.309	0.11707
		25	75.64	1.322	0.12125
		30	74.92	1.335	0.12543
		35	74.20	1.348	0.12961
		40	73.49	1.361	0.13379
		45	72.78	1.374	0.13797
		50	72.09	1.387	0.14215
		55	71.39	1.401	0.14633
	3	0	70.71	1.414	0.15052
		5	70.03	1.428	0.15470
		10	69.36	1.442	0.15888
		15	68.70	1.456	0.16306
		20	68.04	1.470	0.16724
		25	67.39	1.484	0.17142
		30	66.74	1.498	0.17560
		35	66.10	1.513	0.17978
		40	65.47	1.527	0.18396
		45	64.84	1.542	0.18814
		50	64.22	1.557	0.19233
		55	63.61	1.572	0.19651
	4	0	63.00	1.587	0.20069
		5	62.39	1.603	0.20487
		10	61.79	1.618	0.20905
		15	61.20	1.634	0.21323
		20	60.62	1.650	0.21741
		25	60.04	1.666	0.22159
		30	59.46	1.682	0.22577
		35	58.89	1.698	0.22995
		40	58.33	1.714	0.23414
		45	57.77	1.731	0.23832
		50	57.21	1.748	0.24250
		55	56.67	1.765	0.24668
	5	0	56.12	1.782	0.25086
		10	55.05	1.816	0.25922
		20	54.00	1.852	0.26758
		30	52.97	1.888	0.27595
		40	51.96	1.924	0.28431
		50	50.97	1.962	0.29267
	6	0	50.00	2.000	0.30103
		10	49.05	2.039	0.30939
		20	48.11	2.079	0.31776
		30	47.19	2.119	0.32612
		40	46.29	2.160	0.33448
		50	45.41	2.202	0.34284
	7	0	44.54	2.245	0.35120
		10	43.70	2.289	0.35957
		20	42.86	2.333	0.36793

t: d	t: h	t: min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
		30	42.04	2.378	0.37629
		40	41.24	2.425	0.38465
		50	40.46	2.472	0.39301
	8	0	39.68	2.520	0.40137
		10	38.93	2.569	0.40974
		20	38.19	2.619	0.41810
		30	37.46	2.670	0.42646
		40	36.74	2.722	0.43482
		50	36.04	2.775	0.44318
	9	0	35.36	2.828	0.45155
		10	34.68	2.883	0.45991
		20	34.02	2.939	0.46827
		30	33.37	2.997	0.47663
		40	32.73	3.055	0.48499
		50	32.11	3.114	0.49336
	10	0	31.50	3.175	0.50172
		10	30.90	3.237	0.51008
		20	30.31	3.299	0.51844
		30	29.73	3.364	0.52680
		40	29.16	3.429	0.53517
		50	28.61	3.496	0.54353
	11	0	28.06	3.564	0.55189
		10	27.53	3.633	0.56025
		20	27.00	3.704	0.56861
		30	26.49	3.776	0.57698
		40	25.98	3.849	0.58534
		50	25.49	3.924	0.59370
	12	0	25.00	4.000	0.60206
		20	24.06	4.157	0.61879
		40	23.15	4.320	0.63551
	13	0	22.27	4.490	0.65223
		20	21.43	4.666	0.66896
		40	20.62	4.849	0.68568
	14	0	19.84	5.040	0.70241
		20	19.09	5.238	0.71913
		40	18.37	5.443	0.73585
	15	0	17.68	5.657	0.75258
		20	17.01	5.879	0.76930
		40	16.37	6.110	0.78603
	16	0	15.75	6.350	0.80275
		20	15.15	6.599	0.81947
		40	14.58	6.858	0.83620
	17	0	14.03	7.127	0.85292
		20	13.50	7.407	0.86965
		40	12.99	7.698	0.88637
	18	0	12.50	8.000	0.90309
		20	12.03	8.314	0.91982
		40	11.57	8.641	0.93654
	19	0	11.14	8.980	0.95327
		20	10.72	9.332	0.96999
		40	10.31	9.699	0.98671
	20	0	9.92	10.079	1.00344
		20	9.55	10.475	1.02016
		40	9.19	10.886	1.03689
	21	0	8.84	11.314	1.05361
		20	8.50	11.758	1.07033
		40	8.18	12.220	1.08706
	22	0	7.87	12.699	1.10378
		20	7.58	13.198	1.12051
		40	7.29	13.716	1.13723
	23	0	7.02	14.255	1.15395
		20	6.75	14.814	1.17068
		40	6.50	15.396	1.18740
1	0		6.25	16.000	1.20412
	1		5.57	17.960	1.25430
	2		4.96	20.159	1.30447
	3		4.42	22.628	1.35464
	4		3.94	25.399	1.40481
	5		3.51	28.509	1.45498
	6		3.12	32.000	1.50516
	7		2.78	35.919	1.55533
	8		2.48	40.318	1.60550
	9		2.21	45.256	1.65567
	10		1.97	50.798	1.70584
	11		1.75	57.018	1.75602
	12		1.56	64.001	1.80619
	13		1.39	71.839	1.85636
	14		1.24	80.636	1.90653
	15		1.10	90.511	1.95670
	16		0.98	101.596	2.00687
	17		0.88	114.037	2.05705
	18		0.78	128.003	2.10722
	19		0.70	143.678	2.15739
	20		0.62	161.273	2.20756
	21		0.55	181.023	2.25773
	22		0.49	203.192	2.30791

Tellurium-132

half-life 78 h

t: d	t: h	t: min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100.00	1.000	0.00000
	1		99.12	1.009	0.00386
	2		98.24	1.018	0.00772
	3		97.37	1.027	0.01158
	4		96.51	1.036	0.01544
	5		95.65	1.045	0.01930
	6		94.81	1.055	0.02316
	7		93.97	1.064	0.02702
	8		93.14	1.074	0.03087
	9		92.31	1.083	0.03473
	10		91.50	1.093	0.03859
	11		90.69	1.103	0.04245
	12		89.89	1.113	0.04631
	13		89.09	1.122	0.05017
	14		88.30	1.132	0.05403
	15		87.52	1.143	0.05789
	16		86.75	1.153	0.06175
	17		85.98	1.163	0.06561
	18		85.22	1.173	0.06947
	19		84.46	1.184	0.07333
	20		83.72	1.195	0.07719
	21		82.98	1.205	0.08105
	22		82.24	1.216	0.08491
	23		81.51	1.227	0.08877
1	0		80.79	1.238	0.09262
	1		80.08	1.249	0.09648
	2		79.37	1.260	0.10034
	3		78.67	1.271	0.10420
	4		77.97	1.283	0.10806
	5		77.28	1.294	0.11192
	6		76.60	1.306	0.11578
	7		75.92	1.317	0.11964
	8		75.25	1.329	0.12350
	9		74.58	1.341	0.12736
	10		73.92	1.353	0.13122
	11		73.27	1.365	0.13508
	12		72.62	1.377	0.13894
	13		71.98	1.389	0.14280
	14		71.34	1.402	0.14666
	15		70.71	1.414	0.15052
	16		70.08	1.427	0.15437
	17		69.46	1.440	0.15823
	18		68.85	1.452	0.16209
	19		68.24	1.465	0.16595
	20		67.64	1.478	0.16981
	21		67.04	1.492	0.17367
	22		66.45	1.505	0.17753
	23		65.86	1.518	0.18139
2	0		65.28	1.532	0.18525
	1		64.70	1.546	0.18911
	2		64.13	1.559	0.19297
	3		63.56	1.573	0.19683
	4		63.00	1.587	0.20069
	5		62.44	1.602	0.20455
	6		61.89	1.616	0.20841
	7		61.34	1.630	0.21227
	8		60.80	1.645	0.21612
	9		60.26	1.660	0.21998
	10		59.73	1.674	0.22384
	11		59.20	1.689	0.22770
	12		58.67	1.704	0.23156
	13		58.15	1.720	0.23542
	14		57.64	1.735	0.23928
	15		57.13	1.750	0.24314
	16		56.62	1.766	0.24700
	17		56.12	1.782	0.25086
	18		55.63	1.798	0.25472
	19		55.13	1.814	0.25858
	20		54.65	1.830	0.26244
	21		54.16	1.846	0.26630
	22		53.68	1.863	0.27016
	23		53.21	1.879	0.27402
3	0		52.74	1.896	0.27787
	1		52.27	1.913	0.28173
	2		51.81	1.930	0.28559
	3		51.35	1.947	0.28945
	4		50.90	1.965	0.29331
	5		50.45	1.982	0.29717
	6		50.00	2.000	0.30103
	7		49.56	2.018	0.30489
	8		49.12	2.036	0.30875
	9		48.68	2.054	0.31261
	10		48.25	2.072	0.31647
	11		47.83	2.091	0.32033
	12		47.40	2.110	0.32419
	13		46.98	2.128	0.32805
	14		46.57	2.147	0.33191
	15		46.16	2.167	0.33577
	16		45.75	2.186	0.33962
	17		45.34	2.205	0.34348
	18		44.94	2.225	0.34734
	19		44.54	2.245	0.35120
	20		44.15	2.265	0.35506
	21		43.76	2.285	0.35892
	22		43.37	2.306	0.36278
	23		42.99	2.326	0.36664
4	0		42.61	2.347	0.37050
	1		42.23	2.368	0.37436
	2		41.86	2.389	0.37822
	3		41.49	2.410	0.38208
	4		41.12	2.432	0.38594
	5		40.76	2.454	0.38980
	6		40.40	2.475	0.39366

t d	t h	t min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	7		40 04	2 498	0 39752
	8		39 68	2 520	0 40137
	9		39 33	2 542	0 40523
	10		38 99	2 565	0 40909
	11		38 64	2 588	0 41295
	12		38 30	2 611	0 41681
	13		37 96	2 634	0 42067
	14		37 62	2 658	0 42453
	15		37 29	2 682	0 42839
	16		36 96	2 706	0 43225
	17		36 63	2 730	0 43611
	18		36 31	2 754	0 43997
	19		35 99	2 779	0 44383
	20		35 67	2 803	0 44769
	21		35 36	2 828	0 45155
	22		35 04	2 854	0 45541
	23		34 73	2 879	0 45927
5	0		34 43	2 905	0 46312
	1		34 12	2 931	0 46698
	2		33 82	2 957	0 47084
	3		33 53	2 983	0 47470
	4		33 22	3 010	0 47856
	5		32 93	3 037	0 48242
	6		32 64	3 064	0 48628
	7		32 35	3 091	0 49014
	8		32 06	3 119	0 49400
	9		31 78	3 147	0 49786
	10		31 50	3 175	0 50172
	11		31 22	3 203	0 50558
	12		30 94	3 232	0 50944
	13		30 67	3 261	0 51330
	14		30 40	3 290	0 51716
	15		30 13	3 319	0 52102
	16		29 86	3 349	0 52487
	17		29 60	3 379	0 52873
	18		29 34	3 409	0 53259
	19		29 08	3 439	0 53645
	20		28 82	3 470	0 54031
	21		28 56	3 501	0 54417
	22		28 31	3 532	0 54803
	23		28 06	3 564	0 55189
6	0		27 81	3 595	0 55575
	1		27 57	3 628	0 55961
	2		27 32	3 660	0 56347
	3		27 08	3 693	0 56733
	4		26 84	3 726	0 57119
	5		26 60	3 759	0 57505
	6		26 37	3 792	0 57891
	7		26 14	3 826	0 58277
	8		25 90	3 860	0 58662
	9		25 68	3 895	0 59048
	10		25 45	3 930	0 59434
	11		25 22	3 965	0 59820
	12		25 00	4 000	0 60206
	13		24 78	4 036	0 60592
	14		24 56	4 072	0 60978
	15		24 34	4 108	0 61364
	16		24 13	4 145	0 61750
	17		23 91	4 182	0 62136
	18		23 70	4 219	0 62522
	19		23 49	4 257	0 62908
	20		23 28	4 295	0 63294
	21		23 08	4 333	0 63680
	22		22 87	4 372	0 64066
	23		22 67	4 411	0 64452
7	0		22 47	4 450	0 64837
	6		21 30	4 694	0 67153
	12		20 20	4 951	0 69469
	18		19 15	5 222	0 71784
8	0		18 16	5 508	0 74100
	6		17 21	5 810	0 76416
	12		16 32	6 128	0 78731
	18		15 47	6 464	0 81047
9	0		14 67	6 817	0 83362
	6		13 91	7 191	0 85678
	12		13 18	7 585	0 87994
	18		12 50	8 000	0 90309
10	0		11 85	8 438	0 92625
	12		10 65	9 388	0 97256
11	0		9 57	10 444	1 01897
	12		8 61	11 619	1 06519
12	0		7 74	12 927	1 11150
	12		6 95	14 382	1 15781
13	0		6.25	16 000	1 20412
	12		5 62	17 801	1 25044
14	0		5 05	19 804	1 29675
	12		4 54	22 032	1 34306
15			4 08	24 512	1 38937
16			3 30	30 139	1 48200
17			2 66	37 551	1 57462
18			2 15	46 478	1 66725
19			1 74	57 527	1 75987

Iodine-125

half life 60 d

t d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100 00	1 000	0 00000
1	98 85	1 012	0 00502
2	97 72	1 023	0 01003
3	96 59	1 035	0 01505
4	95 48	1 047	0 02007
5	94 39	1 059	0 02509
6	93 30	1 072	0 03010
7	92 23	1 084	0 03512
8	91 17	1 097	0 04014
9	90 13	1 110	0 04515
10	89 09	1 122	0 05017
11	88 07	1 136	0 05519
12	87 06	1 149	0 06021
13	86 06	1 162	0 06522
14	85 07	1 176	0 07024
15	84 09	1 189	0 07526
16	83 12	1 203	0 08027
17	82 17	1 217	0 08529
18	81 23	1 231	0 09031
19	80 29	1 245	0 09533
20	79 37	1 260	0 10034
21	78 46	1 275	0 10536
22	77 56	1 289	0 11038
23	76 67	1 304	0 11540
24	75.79	1 320	0 12041
25	74 92	1 335	0 12543
26	74 05	1 350	0 13045
27	73 20	1 366	0 13546
28	72 36	1 383	0 14048
29	71 53	1 398	0 14550
30	70 71	1 414	0 15052
31	69 90	1 431	0 15553
32	69 10	1 447	0 16055
33	68 30	1 464	0 16557
34	67 52	1 481	0 17058
35	66 74	1 498	0 17560
36	65 98	1 516	0 18062
37	65 22	1 533	0 18564
38	64 47	1 551	0 19065
39	63 73	1 569	0 19567
40	63 00	1 587	0 20069
41	62 27	1 606	0 20570
42	61 56	1 625	0 21072
43	60 85	1 643	0 21574
44	60 15	1 662	0 22076
45	59 46	1 682	0 22577
46	58 78	1 701	0 23079
47	58 10	1 721	0 23581
48	57 43	1 741	0 24082
49	56 78	1 761	0 24584
50	56 12	1 782	0 25086
51	55 48	1 803	0 25588
52	54 84	1 823	0 26089
53	54 21	1 845	0 26591
54	53 59	1 866	0 27093
55	52 97	1 888	0 27595
56	52 36	1 910	0 28096
57	51 76	1 932	0 28598
58	51 17	1 954	0 29100
59	50 58	1 977	0 29601
60	50 00	2 000	0 30103
62	48 86	2 047	0 31107
64	47 74	2 095	0 32110
66	46 65	2 144	0 33113
68	45 59	2 194	0 34117
70	44 54	2 245	0 35120
72	43 53	2 297	0 36124
74	42 53	2 351	0 37127
76	41 56	2 406	0 38131
78	40 61	2 462	0 39134
80	39 68	2 520	0 40137
82	38 78	2 579	0 41141
84	37 89	2 639	0 42144
86	37 03	2 701	0 43149
88	36 18	2 764	0 44151
90	35 36	2 828	0 45155
92	34 55	2 895	0 46158
94	33 76	2 962	0 47162
96	32 99	3 031	0 48165
98	32 23	3 102	0 49168
100	31 50	3 175	0 50172
102	30 78	3 249	0 51175
104	30 08	3 325	0 52179
106	29 39	3 403	0 53182
108	28 72	3 482	0 54186
110	29 06	3 564	0 55189
112	27 42	3 647	0 56192
114	26 79	3 732	0 57196
116	26 18	3 819	0 58199
118	25 58	3 909	0 59203
124	23 87	4 189	0 62213
126	23 33	4 287	0 63217
128	22 79	4 387	0 64220
130	22 27	4 490	0 65223
132	21 76	4 595	0 66227
134	21 27	4 702	0 67230
136	20 78	4 812	0 68234
138	20 31	4 925	0 69237
140	19 84	5 040	0 70241
145	18 73	5 339	0 72749
150	17 68	5 657	0 75258
155	16 69	5 993	0 77766
160	15 75	6 350	0 80275
165	14 86	6 727	0 82784
170	14 03	7 127	0 85292
175	13 24	7 551	0 87801
180	12 50	8 000	0 90309
185	11 80	8 476	0 92818
190	11 14	8 980	0 95327
195	10 51	9 514	0 97835
200	9 92	10 079	1 00344
205	9 36	10 679	1 02852
210	8 84	11 314	1 05361
215	8 34	11 987	1 07870
220	7 87	12 699	1 10378
225	7 43	13 454	1 12887
230	7 02	14 255	1 15395
235	6 62	15 102	1 17904
240	6 25	16 000	1 20412
245	5 90	16 952	1 22921
250	5 57	17 960	1 25430
255	5 26	19 028	1 27938
260	4 96	20 159	1 30447
265	4 68	21 358	1 32955
270	4 42	22 629	1 35464
275	4 17	23 973	1 37973
280	3 94	25 399	1 40481
285	3 72	26 909	1 42990
290	3 51	28 509	1 45498
295	3 31	30 204	1 48007
300	3 12	32 000	1 50516
310	2 78	35 919	1 55533
320	2 48	40 318	1 60550
330	2 21	45 256	1 65567
340	1 97	50 798	1 70584
350	1 75	57,018	1 75602
360	1 56	64 001	1 80619
370	1 39	71 839	1 85636
380	1 24	80 636	1 90653
390	1 10	90 511	1 95670
400	0 98	101 596	2 00687
410	0 88	114 037	2 05705
420	0 78	128 003	2 10722
430	0 70	143 678	2 15739
440	0 62	161 273	2 20756
450	0 55	181 023	2 25773
460	0 49	203 192	2 30791

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half life 8 04 d

t d	t h	t min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100 00	1 000	0 00000
	3		98 93	1 011	0 00468
	6		97 87	1 022	0 00936
	9		96 82	1 033	0 01404
	12		95 78	1 044	0 01872
	15		94 75	1 055	0 02340
	18		93 74	1 067	0 02808
	21		92 73	1 078	0 03276
1	0		91 74	1 090	0 03744
	3		90 76	1 102	0 04212
	6		89 78	1 114	0 04680
	9		88 82	1 126	0 05148
	12		87 87	1 138	0 05616
	15		86 93	1 150	0 06084
	18		86 00	1 163	0 06552
	21		85 07	1 175	0 07020
2	0		[illegible]	[illegible]	[illegible]
	3		[illegible]	[illegible]	[illegible]
	6		[illegible]	[illegible]	[illegible]
	9		[illegible]	[illegible]	[illegible]
	12		[illegible]	[illegible]	[illegible]
	15		[illegible]	[illegible]	[illegible]
	18		[illegible]	[illegible]	[illegible]
	21		[illegible]	[illegible]	[illegible]
3	0		[illegible]	[illegible]	[illegible]
	3		[illegible]	[illegible]	[illegible]
	6		[illegible]	[illegible]	[illegible]
	9		[illegible]	[illegible]	[illegible]
	12		[illegible]	[illegible]	[illegible]
4	0		70 83	1 412	[illegible]
	3		70 07	1 427	[illegible]
	6		69 32	1 443	[illegible]
	9		68 58	1 458	[illegible]
	12		67 84	1 474	[illegible]
	15		67 12	1 490	[illegible]
	18		66 40	1 506	[illegible]
	21		65 69	1 522	[illegible]
5	0		64 98	1 539	[illegible]
	3		64 29	1 556	[illegible]
	6		63 60	1 572	[illegible]
	9		62 91	1 589	[illegible]
	12		62 24	1 607	[illegible]
	15		61 57	1 624	[illegible]
	18		60 91	1 642	[illegible]
	21		60 26	1 659	[illegible]
6	0		59 61	1 677	[illegible]
	3		58 98	1 696	[illegible]
	6		58 34	1 714	[illegible]
	9		57 72	1 733	[illegible]
	12		57.10	1 751	[illegible]
	15		56 49	1 770	[illegible]
	18		55 88	1 789	[illegible]
	21		55 28	1 809	[illegible]
7	0		54 69	1 828	[illegible]
	6		53 52	1 868	[illegible]
	12		52 38	1 909	[illegible]
	18		51 27	1 951	[illegible]
8	0		50 17	1 993	[illegible]
	6		49 10	2 037	[illegible]
	12		48 06	2 081	[illegible]
	18		47 03	2 126	[illegible]
9	0		46 03	2 173	[illegible]
	6		45 05	2 220	[illegible]
	12		44 09	2 268	[illegible]
	18		43 15	2 319	[illegible]
10	0		42 23	2 368	[illegible]
	6		41 33	2 420	[illegible]
	12		40 44	2 473	[illegible]
	18		39 58	2 526	[illegible]
11	0		38 74	2 581	[illegible]
	6		37 91	2 638	[illegible]
	12		37 10	2 695	[illegible]
	18		36 31	2 754	[illegible]
12	0		35 54	2 814	[illegible]
	6		34 78	2 875	[illegible]
	12		34 04	2 938	[illegible]
	18		33 31	3 002	[illegible]
13	0		32 60	3 067	[illegible]
	6		31 91	3 134	[illegible]
	12		31 23	3 202	[illegible]
	18		30 56	3 272	[illegible]
14	0		29 91	3 343	[illegible]
	6		29 27	3 416	[illegible]
	12		28 65	3 491	[illegible]
	18		28 04	3 567	[illegible]
15	0		27 44	3 644	[illegible]
	6		26 85	3 724	[illegible]
	12		26 28	3 805	[illegible]
	18		25 72	3 888	[illegible]
16	0		25 17	3 973	[illegible]
	12		24 11	4 148	[illegible]
17	0		23 09	4 330	[illegible]
	12		22 12	4 521	[illegible]
18	0		21 19	4 720	[illegible]
	12		20 29	4 928	[illegible]
19	0		19 44	5 145	[illegible]
	12		18 62	5 372	[illegible]
20	0		17 83	5 608	[illegible]
	12		17 08	5 855	[illegible]
21	0		16 36	6 113	[illegible]
	12		15 67	6 383	[illegible]
22	0		15 01	6 664	[illegible]
	12		14 37	6 957	[illegible]
23	0		13 77	7 264	[illegible]
	12		13 19	7.584	[illegible]
24	0		12 63	7 918	[illegible]
	12		12 10	8 266	[illegible]

Iodine-132

half-life 2.3 h

t: d	t: h	t: min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
		0	100.00	1.000	0.00000
		2	99.00	1.010	0.00436
		4	98.01	1.020	0.00873
		6	97.03	1.031	0.01309
		8	96.06	1.041	0.01745
		10	95.10	1.052	0.02181
		12	94.15	1.062	0.02618
		14	93.21	1.073	0.03054
		16	92.28	1.084	0.03490
		18	91.36	1.095	0.03926
		20	90.44	1.106	0.04363
		22	89.54	1.117	0.04799
		24	88.64	1.128	0.05235
		26	87.76	1.140	0.05672
		28	86.88	1.151	0.06108
		30	86.01	1.163	0.06544
		32	85.15	1.174	0.06980
		34	84.30	1.186	0.07417
		36	83.46	1.198	0.07853
		38	82.62	1.210	0.08289
		40	81.80	1.223	0.08726
		42	80.98	1.235	0.09162
		44	80.17	1.247	0.09598
		46	79.37	1.260	0.10034
		48	78.58	1.273	0.10471
		50	77.79	1.285	0.10907
		52	77.01	1.298	0.11343
		54	76.24	1.312	0.11779
		56	75.48	1.325	0.12216
		58	74.73	1.338	0.12652
	1	0	73.98	1.352	0.13088
		2	73.24	1.365	0.13525
		4	72.51	1.379	0.13961
		6	71.78	1.393	0.14397
		8	71.07	1.407	0.14833
		10	70.36	1.421	0.15270
		12	69.65	1.436	0.15706
		14	68.96	1.450	0.16142
		16	68.27	1.465	0.16579
		18	67.59	1.480	0.17015
		20	66.91	1.495	0.17451
		22	66.24	1.510	0.17887
		24	65.58	1.525	0.18324
		26	64.92	1.540	0.18760
		28	64.27	1.556	0.19196
		30	63.63	1.572	0.19632
		32	63.00	1.587	0.20069
		34	62.37	1.603	0.20505
		36	61.74	1.620	0.20941
		38	61.13	1.636	0.21378
		40	60.51	1.652	0.21814
		42	59.91	1.669	0.22250
		44	59.31	1.686	0.22686
		46	58.72	1.703	0.23123
		48	58.13	1.720	0.23559
		50	57.55	1.738	0.23995
		52	56.98	1.755	0.24432
		54	56.41	1.773	0.24868
		56	55.84	1.791	0.25304
		58	55.28	1.809	0.25740
	2	0	54.73	1.827	0.26177
		2	54.18	1.846	0.26613
		4	53.64	1.864	0.27049
		6	53.11	1.883	0.27485
		8	52.58	1.902	0.27922
		10	52.05	1.921	0.28358
		12	51.53	1.941	0.28794
		14	51.01	1.960	0.29231
		16	50.50	1.980	0.29667
		18	50.00	2.000	0.30103
		20	49.50	2.020	0.30539
		22	49.01	2.041	0.30976
		24	48.52	2.061	0.31412
		26	48.03	2.082	0.31848
		28	47.55	2.103	0.32285
		30	47.08	2.124	0.32721
		32	46.60	2.146	0.33157
		34	46.14	2.167	0.33593
		36	45.68	2.189	0.34030
		38	45.22	2.211	0.34466
		40	44.77	2.234	0.34902
		45	43.66	2.290	0.35993
		50	42.58	2.349	0.37084
		55	41.52	2.408	0.38174
	3	0	40.49	2.470	0.39265
		5	39.49	2.533	0.40356
		10	38.51	2.597	0.41446
		15	37.55	2.663	0.42537
		20	36.62	2.731	0.43628
		25	35.71	2.800	0.44718
		30	34.83	2.871	0.45809
		35	33.96	2.944	0.46900
		40	33.12	3.019	0.47990
		45	32.30	3.096	0.49081
		50	31.50	3.175	0.50172
		55	30.72	3.256	0.51263
	4	0	29.95	3.338	0.52353
		5	29.21	3.423	0.53444
		10	28.49	3.510	0.54535
		15	27.78	3.600	0.55625
		20	27.09	3.691	0.56716
		25	26.42	3.785	0.57807
		30	25.76	3.881	0.58897
		35	25.13	3.980	0.59988
		40	24.50	4.081	0.61079
		45	23.89	4.185	0.62169
		50	23.30	4.291	0.63260
		55	22.72	4.401	0.64351
	5	0	22.16	4.512	0.65442
		5	21.61	4.627	0.66532
		10	21.08	4.745	0.67623
		15	20.55	4.866	0.68714
		20	20.04	4.989	0.69804
		25	19.55	5.116	0.70895
		30	19.06	5.246	0.71986
		35	18.59	5.380	0.73076
		40	18.13	5.517	0.74167
		45	17.68	5.657	0.75258
		50	17.24	5.801	0.76348
		55	16.81	5.948	0.77439
	6	0	16.39	6.100	0.78530
		5	15.99	6.255	0.79621
		10	15.59	6.414	0.80711
		15	15.20	6.577	0.81802
		20	14.83	6.744	0.82893
		25	14.46	6.916	0.83983
		30	14.10	7.092	0.85074
		35	13.75	7.272	0.86165
		40	13.41	7.457	0.87255
		45	13.08	7.646	0.88346
		50	12.75	7.841	0.89437
		55	12.44	8.040	0.90527
	7	0	12.13	8.245	0.91618
		5	11.83	8.455	0.92709
		10	11.53	8.670	0.93800
		15	11.25	8.890	0.94890
		20	10.97	9.116	0.95981
		25	10.70	9.348	0.97072
		30	10.43	9.586	0.98162
		35	10.17	9.829	0.99253
		40	9.92	10.079	1.00344
		45	9.68	10.336	1.01434
		50	9.44	10.599	1.02525
		55	9.20	10.868	1.03616
	8	0	8.97	11.145	1.04707
		5	8.75	11.428	1.05797
		10	8.53	11.719	1.06888
		15	8.32	12.017	1.07979
		20	8.12	12.322	1.09069
		25	7.91	12.636	1.10160
		30	7.72	12.957	1.11251
		35	7.53	13.287	1.12341
		40	7.34	13.624	1.13432
		45	7.16	13.971	1.14523
		50	6.98	14.326	1.15613
		55	6.81	14.691	1.16704
	9	0	6.64	15.064	1.17795
		5	6.47	15.447	1.18886
		10	6.31	15.840	1.19976
		15	6.16	16.243	1.21067
		20	6.00	16.656	1.22158
		25	5.85	17.080	1.23248
		30	5.71	17.514	1.24339
		35	5.57	17.960	1.25430
		40	5.43	18.416	1.26520
		45	5.30	18.885	1.27611
		50	5.16	19.365	1.28702
		55	5.04	19.857	1.29792
	10	0	4.91	20.363	1.30883
		10	4.67	21.411	1.33065
		20	4.44	22.514	1.35246
		30	4.22	23.674	1.37427
		40	4.02	24.894	1.39609
		50	3.82	26.176	1.41790
	11	0	3.63	27.524	1.43971
		10	3.46	28.942	1.46153
		20	3.29	30.433	1.48334
		30	3.12	32.000	1.50516
		40	2.97	33.649	1.52697
		50	2.83	35.382	1.54878
	12	0	2.69	37.205	1.57060
		10	2.56	39.121	1.59241
		20	2.43	41.136	1.61423
		30	2.31	43.255	1.63604
		40	2.20	45.483	1.65785
		50	2.09	47.826	1.67967
	13	0	1.99	50.290	1.70148
		10	1.89	52.880	1.72329
		20	1.80	55.604	1.74511
		30	1.71	58.469	1.76692
		40	1.63	61.480	1.78874
		50	1.55	64.647	1.81055
	14	0	1.47	67.977	1.83236
		10	1.40	71.479	1.85418
		20	1.33	75.161	1.87599
		30	1.27	79.032	1.89781
		40	1.20	83.103	1.91962
		50	1.14	87.384	1.94143
	15	0	1.09	91.886	1.96325
		10	1.03	96.619	1.98506
		20	0.98	101.596	2.00687
		30	0.94	106.829	2.02869
		40	0.89	112.332	2.05050
		50	0.85	118.118	2.07232
	16	0	0.81	124.202	2.09413
		10	0.77	130.600	2.11594
		20	0.73	137.328	2.13776
		30	0.69	144.402	2.15957
		40	0.66	151.840	2.18139
		50	0.63	159.661	2.20320
	17	0	0.60	167.886	2.22501
		10	0.57	176.534	2.24683
		20	0.54	185.627	2.26864
		30	0.51	195.189	2.29045

Caesium-137

half-life 30 y

t: d	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.00000
100	99.37	1.006	0.00275
200	98.74	1.012	0.00550
300	98.12	1.019	0.00824
400	97.50	1.025	0.01099
500	96.89	1.032	0.01374
600	96.28	1.038	0.01648
700	95.67	1.045	0.01923
800	95.07	1.051	0.02198
900	94.47	1.058	0.02473
1000	93.87	1.065	0.02747
1100	93.28	1.072	0.03022
1200	92.69	1.078	0.03297
1300	92.11	1.085	0.03572
1400	91.52	1.092	0.03846
1500	90.95	1.099	0.04121
1600	90.37	1.106	0.04396
1700	89.80	1.113	0.04670
1800	89.24	1.120	0.04945
1900	88.67	1.127	0.05220
2000	88.12	1.134	0.05495
2200	87.01	1.149	0.06044
2400	85.91	1.163	0.06594
2600	84.83	1.178	0.07143
2800	83.77	1.193	0.07693
3000	82.71	1.208	0.08242
3200	81.67	1.224	0.08792
3400	80.65	1.239	0.09341
3600	79.63	1.255	0.09890
3800	78.63	1.271	0.10440
4000	77.64	1.287	0.10989
4200	76.67	1.304	0.11539
4400	75.70	1.320	0.12088
4600	74.75	1.337	0.12638
4800	73.81	1.354	0.13187
5000	72.88	1.372	0.13737
5200	71.97	1.389	0.14286
5400	71.06	1.407	0.14836
5600	70.17	1.425	0.15385
5800	69.29	1.443	0.15935
6000	68.42	1.461	0.16484
6200	67.56	1.480	0.17033
6400	66.71	1.499	0.17583
6600	65.87	1.518	0.18132
6800	65.04	1.537	0.18682
7000	64.22	1.557	0.19231
7200	63.42	1.576	0.19781
7400	62.62	1.596	0.20330
7600	61.83	1.617	0.20880
7800	61.05	1.637	0.21429
8000	60.29	1.658	0.21979
8200	59.53	1.679	0.22528
8400	58.78	1.701	0.23078
8600	58.04	1.722	0.23627
8800	57.31	1.744	0.24177
9000	56.59	1.767	0.24726
9200	55.88	1.789	0.25275
9400	55.18	1.812	0.25825
9600	54.48	1.835	0.26374
9800	53.80	1.858	0.26924
10000	53.12	1.882	0.27473
10200	52.45	1.906	0.28023
10400	51.79	1.930	0.28572
10600	51.14	1.955	0.29122
10800	50.50	1.980	0.29671
11000	49.86	2.005	0.30221
11200	49.24	2.030	0.30770
11400	48.62	2.056	0.31320
11600	48.01	2.083	0.31869
11800	47.40	2.109	0.32419
12000	46.81	2.136	0.32968
12200	46.22	2.163	0.33517
12400	45.64	2.191	0.34067
12600	45.06	2.219	0.34616
12800	44.50	2.247	0.35166
13000	43.94	2.275	0.35715
13200	43.39	2.304	0.36265
13400	42.84	2.334	0.36814
13600	42.30	2.363	0.37364
13800	41.77	2.394	0.37913
14000	41.25	2.424	0.38463
14200	40.73	2.455	0.39012
14400	40.21	2.486	0.39562
14600	39.71	2.518	0.40111
14800	39.21	2.550	0.40660
15000	38.72	2.582	0.41210
15200	38.23	2.615	0.41759
15400	37.75	2.649	0.42309
15600	37.27	2.682	0.42858
15800	36.81	2.716	0.43408
16000	36.34	2.751	0.43957
16500	35.21	2.839	0.45331
17000	34.12	2.931	0.46705
17500	33.05	3.025	0.48078
18000	32.02	3.122	0.49452
18500	31.03	3.222	0.50826
19000	30.06	3.326	0.52199
19500	29.13	3.433	0.53573
20000	28.22	3.543	0.54947
20500	27.34	3.657	0.56320
21000	26.49	3.775	0.57694
21500	25.66	3.896	0.59068
22000	24.87	4.021	0.60441
22500	24.09	4.150	0.61815
23000	23.34	4.284	0.63189
23500	22.61	4.422	0.64562
24000	21.91	4.564	0.65936
24500	21.23	4.710	0.67309
25000	20.57	4.862	0.68683
25500	19.93	5.018	0.70057
26000	19.31	5.179	0.71430
26500	18.71	5.346	0.72804
27000	18.12	5.517	0.74178
27500	17.56	5.695	0.75551
28000	17.01	5.878	0.76925
28500	16.48	6.067	0.78299
29000	15.97	6.262	0.79672
29500	15.47	6.463	0.81046
30000	14.99	6.671	0.82420
30500	14.52	6.885	0.83793
31000	14.07	7.106	0.85167
31500	13.63	7.335	0.86540
32000	13.21	7.570	0.87914
32500	12.80	7.814	0.89288
33000	12.40	8.065	0.90661
33500	12.01	8.324	0.92035
34000	11.64	8.591	0.93408
34500	11.28	8.867	0.94782
35000	10.93	9.152	0.96156
35500	10.59	9.446	0.97529
36000	10.26	9.750	0.98903
36500	9.94	10.064	1.00277
37000	9.63	10.387	1.01651
37500	9.33	10.721	1.03025
38000	9.04	11.065	1.04398
38500	8.76	11.421	1.05772
39000	8.48	11.788	1.07146
39500	8.22	12.167	1.08519
40000	7.96	12.558	1.09893
40500	7.71	12.961	1.11267
41000	7.47	13.378	1.12640
41500	7.24	13.808	1.14014
42000	7.02	14.252	1.15388
42500	6.80	14.710	1.16761
43000	6.59	15.182	1.18135
43500	6.38	15.670	1.19509
44000	6.18	16.174	1.20882
44500	5.99	16.693	1.22256
45000	5.80	17.230	1.23630
45500	5.62	17.784	1.25003
46000	5.45	18.355	1.26377
46500	5.28	18.945	1.27751
47000	5.11	19.554	1.29124
47500	4.95	20.182	1.30498
48000	4.80	20.831	1.31872
48500	4.65	21.500	1.33245
49000	4.51	22.191	1.34619
49500	4.37	22.904	1.35993
50000	4.23	23.640	1.37366
50500	4.10	24.400	1.38740
51000	3.97	25.184	1.40114
51500	3.85	25.994	1.41487
52000	3.73	26.829	1.42861
52500	3.61	27.691	1.44235
53000	3.50	28.581	1.45608
53500	3.39	29.499	1.46982
54000	3.28	30.447	1.48356
54500	3.18	31.426	1.49729
55000	3.08	32.436	1.51103
55500	2.99	33.478	1.52477

t (d)	N_t	N_0/N_t	$\log_{10} N_0/N_t$
56000	2.89	34.554	1.53850
56500	2.80	35.664	1.55224
57000	2.72	36.810	1.56598
57500	2.63	37.993	1.57971
58000	2.55	39.214	1.59345
58500	2.47	40.474	1.60719
59000	2.39	41.775	1.62092
59500	2.32	43.117	1.63466
60000	2.25	44.503	1.64840
60500	2.18	45.933	1.66213
61000	2.11	47.409	1.67587
61500	2.04	48.933	1.68960
62000	1.98	50.505	1.70334
62500	1.92	52.129	1.71708
63000	1.86	53.803	1.73081
63500	1.80	55.533	1.74455
64000	1.74	57.317	1.75829
64500	1.69	59.159	1.77202
65000	1.64	61.060	1.78576
65500	1.59	63.022	1.79950
66000	1.54	65.047	1.81323
66500	1.49	67.137	1.82697
67000	1.44	69.295	1.84071
67500	1.40	71.522	1.85444
68000	1.35	73.820	1.86818
68500	1.31	76.192	1.88191
69000	1.27	78.641	1.89565
69500	1.23	81.168	1.90939
70000	1.19	83.776	1.92312
70500	1.16	86.468	1.93686
71000	1.12	89.246	1.95059
71500	1.09	92.114	1.96433
72000	1.05	95.074	1.97806
72500	1.02	98.129	1.99180
73000	0.99	101.285	2.00555
73500	0.96	104.540	2.01928
74000	0.93	107.900	2.03302
74500	0.90	111.367	2.04676
75000	0.87	114.946	2.06050
76000	0.82	122.452	2.08797
77000	0.77	130.449	2.11544
78000	0.72	138.968	2.14292
79000	0.68	148.042	2.17039
80000	0.63	157.711	2.19786
81000	0.60	168.010	2.22534
82000	0.56	178.980	2.25281
83000	0.52	190.668	2.28028
84000	0.49	203.119	2.30775
85000	0.46	216.384	2.33523
86000	0.43	230.515	2.36270
87000	0.41	245.567	2.39017
88000	0.38	261.602	2.41764
89000	0.36	278.691	2.44512
90000	0.34	296.885	2.47259
91000	0.32	316.275	2.50007
92000	0.30	336.927	2.52754
93000	0.28	358.937	2.55502
94000	0.26	382.365	2.58248
95000	0.25	407.348	2.60997
96000	0.23	431.933	2.63742
97000	0.22	462.278	2.66490
98000	0.20	492.465	2.69238
99000	0.19	524.631	2.71985
100000	0.18	558.877	2.74732

Iridium-192
half life 74 d

t (d)	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	100.00	1.000	0.00000
2	98.14	1.019	0.00814
4	96.32	1.038	0.01627
6	94.53	1.058	0.02441
8	92.78	1.078	0.03254
10	91.06	1.098	0.04068
12	89.37	1.119	0.04882
14	87.71	1.140	0.05695
16	86.08	1.162	0.06509
18	84.48	1.184	0.07322
20	82.92	1.206	0.08136
22	81.38	1.229	0.08950
24	79.87	1.252	0.09763
26	78.38	1.276	0.10577
28	76.93	1.300	0.11390
30	75.50	1.324	0.12204
32	74.10	1.350	0.13018
34	72.73	1.375	0.13831
36	71.38	1.401	0.14645
38	70.05	1.428	0.15458
40	68.75	1.455	0.16272
42	67.48	1.482	0.17086
44	66.22	1.510	0.17899
46	64.99	1.539	0.18713
48	63.79	1.568	0.19526
50	62.60	1.597	0.20340
52	61.44	1.628	0.21154
54	60.30	1.658	0.21967
56	59.18	1.690	0.22781
58	58.08	1.722	0.23594
60	57.01	1.754	0.24408
64	54.91	1.821	0.26035
68	52.89	1.891	0.27662
72	50.95	1.963	0.29290
76	49.07	2.038	0.30917
80	47.27	2.116	0.32544
84	45.53	2.196	0.34171
88	43.85	2.280	0.35798
92	42.24	2.367	0.37426
96	40.69	2.458	0.39053
100	39.19	2.552	0.40680
104	37.75	2.649	0.42307
108	36.36	2.750	0.43934
112	35.03	2.855	0.45561
116	33.74	2.964	0.47189
120	32.50	3.077	0.48816
124	31.30	3.195	0.50443
128	30.15	3.317	0.52070
132	29.04	3.443	0.53697
136	27.97	3.575	0.55325
140	26.95	3.711	0.56952
144	25.95	3.853	0.58579
148	25.00	4.000	0.60206
152	24.08	4.153	0.61833
156	23.19	4.311	0.63461
160	22.34	4.476	0.65088
170	20.34	4.915	0.69156
180	18.53	5.398	0.73224
190	16.87	5.928	0.77292
200	15.36	6.510	0.81360
210	13.99	7.150	0.85428
220	12.74	7.852	0.89496
230	11.60	8.623	0.93564
240	10.56	9.469	0.97632
250	9.62	10.399	1.01700
260	8.76	11.420	1.05768
270	7.97	12.542	1.09836
280	7.26	13.773	1.13904
290	6.61	15.126	1.17972
300	6.02	16.611	1.22040
310	5.48	18.242	1.26108
320	4.99	20.033	1.30176
330	4.55	22.001	1.34244
340	4.14	24.161	1.38312
350	3.77	26.534	1.42380
360	3.43	29.139	1.46448
370	3.12	32.000	1.50516
380	2.85	35.143	1.54584
390	2.59	38.594	1.58652
400	2.36	42.383	1.62720
410	2.15	46.545	1.66788
420	1.96	51.116	1.70856
430	1.78	56.135	1.74924
440	1.62	61.647	1.78992
450	1.48	67.701	1.83060
460	1.35	74.349	1.87128
470	1.22	81.650	1.91195
480	1.12	89.667	1.95263
490	1.02	98.472	1.99331
500	0.92	108.142	2.03399
510	0.84	118.761	2.07467
520	0.77	130.423	2.11535
530	0.70	143.230	2.15603
540	0.64	157.295	2.19671
550	0.58	172.741	2.23739
560	0.53	189.703	2.27807
570	0.48	208.331	2.31875

Gold-198
half life 2.7 d

t: d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100.00	1.000	0.00000
	1		98.94	1.010	0.00465
	2		97.88	1.021	0.00929
	3		96.84	1.032	0.01394
	4		95.81	1.043	0.01858
	5		94.79	1.054	0.02323
	6		93.78	1.066	0.02787
	7		92.79	1.077	0.03252
	8		91.80	1.089	0.03716
	9		90.82	1.101	0.04181
	10		89.86	1.112	0.04646
	11		88.90	1.124	0.05110
	12		87.95	1.136	0.05575
	13		87.02	1.149	0.06039
	14		86.09	1.161	0.06504
	15		85.18	1.174	0.06968
	16		84.27	1.186	0.07433
	17		83.37	1.199	0.07897
	18		82.49	1.212	0.08362
	19		81.61	1.225	0.08827
	20		80.74	1.238	0.09291
	21		79.88	1.251	0.09756
	22		79.03	1.265	0.10220
	23		78.19	1.278	0.10685
1	0		77.36	1.292	0.11149
	1		76.54	1.306	0.11614
	2		75.72	1.320	0.12078
	3		74.92	1.334	0.12543
	4		74.12	1.349	0.13008
	5		73.33	1.363	0.13472
	6		72.55	1.378	0.13937
	7		71.78	1.393	0.14401
	8		71.01	1.408	0.14866
	9		70.26	1.423	0.15330
	10		69.51	1.438	0.15795
	11		68.77	1.454	0.16259
	12		68.04	1.469	0.16724
	13		67.32	1.485	0.17188
	14		66.60	1.501	0.17653
	15		65.89	1.517	0.18118
	16		65.19	1.533	0.18582
	17		64.50	1.550	0.19047
	18		63.81	1.567	0.19511
	19		63.13	1.584	0.19976
	20		62.46	1.601	0.20440
	21		61.79	1.618	0.20905
	22		61.14	1.635	0.21369
	23		60.49	1.653	0.21834
2	0		59.84	1.671	0.22299
	1		59.21	1.689	0.22763
	2		58.58	1.707	0.23228
	3		57.95	1.725	0.23692
	4		57.34	1.744	0.24157
	5		56.73	1.762	0.24621
	6		56.12	1.781	0.25086
	7		55.53	1.800	0.25550
	8		54.94	1.820	0.26015
	9		54.35	1.839	0.26480
	10		53.77	1.859	0.26944
	11		53.20	1.879	0.27409
	12		52.63	1.899	0.27873
	13		52.07	1.920	0.28338
	14		51.52	1.940	0.28802
	15		50.97	1.961	0.29267
	16		50.43	1.982	0.29731
	17		49.89	2.004	0.30196
	18		49.36	2.025	0.30661
	19		48.84	2.047	0.31125
	20		48.32	2.069	0.31590
	21		47.80	2.091	0.32054
	22		47.29	2.114	0.32519
	23		46.79	2.137	0.32983
3	0		46.29	2.160	0.33448
	1		45.80	2.183	0.33912
	2		45.31	2.206	0.34377
	3		44.83	2.230	0.34841
	4		44.35	2.254	0.35306
	5		43.88	2.278	0.35771
	6		43.42	2.303	0.36235
	7		42.95	2.328	0.36700
	8		42.50	2.353	0.37164
	9		42.04	2.378	0.37629
	10		41.60	2.403	0.38093
	11		41.15	2.429	0.38558
	12		40.72	2.455	0.39022
	13		40.28	2.482	0.39487
	14		39.86	2.509	0.39952
	15		39.43	2.536	0.40416
	16		39.01	2.563	0.40881
	17		38.60	2.590	0.41345
	18		38.19	2.618	0.41810
	19		37.78	2.646	0.42274
	20		37.38	2.675	0.42739
	21		36.98	2.704	0.43203
	22		36.59	2.733	0.43668
	23		36.20	2.762	0.44133
4	0		35.81	2.792	0.44597
	1		35.43	2.822	0.45062
	2		35.05	2.852	0.45526
	3		34.68	2.883	0.45991
	4		34.31	2.914	0.46455
	5		33.95	2.945	0.46920
	6		33.59	2.977	0.47384
	7		33.23	3.009	0.47849
	8		32.87	3.041	0.48313
	9		32.53	3.074	0.48778
	10		32.18	3.107	0.49243
	11		31.84	3.141	0.49707
	12		31.50	3.174	0.50172
	13		31.16	3.208	0.50636
	14		30.83	3.243	0.51101
	15		30.50	3.278	0.51565
	16		30.18	3.313	0.52030
	17		29.86	3.349	0.52494
	18		29.54	3.385	0.52959
	19		29.23	3.421	0.53424
	20		28.91	3.458	0.53888
	21		28.61	3.495	0.54353
	22		28.30	3.533	0.54817
	23		28.00	3.571	0.55282
5	0		27.70	3.609	0.55746
	6		25.98	3.848	0.58534
	12		24.37	4.104	0.61321
	18		22.85	4.376	0.64108
6	0		21.43	4.666	0.66896
	6		20.10	4.975	0.69683
	12		18.85	5.305	0.72470
	18		17.68	5.656	0.75257
7	0		16.58	6.031	0.78045
	6		15.55	6.431	0.80832
	12		14.58	6.857	0.83619
	18		13.68	7.312	0.86406
8	0		12.83	7.797	0.89194
	6		12.03	8.313	0.91981
	12		11.28	8.865	0.94768
	18		10.58	9.452	0.97555
9	0		9.92	10.079	1.00343
	6		9.30	10.747	1.03131
	12		8.73	11.459	1.05918
	18		8.18	12.219	1.08705
10	0		7.67	13.029	1.11493
	6		7.20	13.893	1.14280
	12		6.75	14.814	1.17067
	18		6.33	15.795	1.19855
11	0		5.94	16.842	1.22642
	6		5.57	17.959	1.25429
	12		5.22	19.149	1.28217
	18		4.90	20.419	1.31004
12	0		4.59	21.772	1.33791
	6		4.31	23.215	1.36578
	12		4.04	24.754	1.39366
	18		3.79	26.395	1.42153
13	0		3.55	28.145	1.44940
	6		3.33	30.010	1.47728
	12		3.13	32.000	1.50515
	18		2.93	34.121	1.53302
14	0		2.75	36.382	1.56090
	6		2.58	38.794	1.58877
	12		2.42	41.365	1.61664
	18		2.27	44.107	1.64452
15	0		2.13	47.031	1.67239
	6		1.99	50.148	1.70026
	12		1.87	53.473	1.72814
	18		1.75	57.017	1.75601
16	0		1.64	60.796	1.78388
	6		1.54	64.826	1.81175
	12		1.45	69.123	1.83963
	18		1.36	73.705	1.86750
17	0		1.27	78.590	1.89537
	6		1.19	83.799	1.92324
	12		1.12	89.353	1.95111
	18		1.05	95.276	1.97899
18	0		0.98	101.594	2.00687
	6		0.92	108.328	2.03474
	12		0.87	115.508	2.06261
	18		0.81	123.164	2.09049
19	0		0.76	131.328	2.11836
	6		0.71	140.034	2.14624
	12		0.67	149.316	2.17411
	18		0.63	159.212	2.20198
20			0.59	169.767	2.22986
25			0.16	612.782	2.78731
30			0.05	2211.900	3.34477
35			0.01	7987.220	3.90240

Mercury-197
half life 65 h

t: d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	0		100.00	1.000	0.00000
	1		98.94	1.011	0.00463
	2		97.89	1.022	0.00926
	3		96.85	1.033	0.01389
	4		95.82	1.044	0.01852
	5		94.81	1.055	0.02316
	6		93.80	1.066	0.02779
	7		92.81	1.078	0.03242
	8		91.82	1.089	0.03705
	9		90.85	1.101	0.04168
	10		89.89	1.113	0.04631
	11		88.93	1.124	0.05094
	12		87.99	1.137	0.05557
	13		87.06	1.149	0.06021
	14		86.13	1.161	0.06484
	15		85.22	1.173	0.06947
	16		84.31	1.186	0.07410
	17		83.42	1.199	0.07873
	18		82.53	1.212	0.08336
	19		81.66	1.225	0.08799
	20		80.79	1.238	0.09262
	21		79.94	1.251	0.09726
	22		79.09	1.264	0.10189
	23		78.25	1.278	0.10652
1	0		77.42	1.292	0.11115
	1		76.60	1.306	0.11578
	2		75.79	1.320	0.12041
	3		74.98	1.334	0.12504

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	4		74.19	1.348	0.12967
	5		73.40	1.362	0.13431
	6		72.62	1.377	0.13894
	7		71.85	1.392	0.14357
	8		71.09	1.407	0.14820
	9		70.33	1.422	0.15283
	10		69.59	1.437	0.15746
	11		68.85	1.452	0.16209
	12		68.12	1.468	0.16672
	13		67.40	1.484	0.17136
	14		66.68	1.500	0.17599
	15		65.98	1.516	0.18062
	16		65.28	1.532	0.18525
	17		64.58	1.548	0.18988
	18		63.90	1.565	0.19451
	19		63.22	1.582	0.19914
	20		62.55	1.599	0.20377
	21		61.89	1.616	0.20841
	22		61.23	1.633	0.21304
	23		60.58	1.651	0.21767
2	0		59.94	1.668	0.22230
	1		59.30	1.686	0.22693
	2		58.67	1.704	0.23156
	3		58.05	1.723	0.23619
	4		57.43	1.741	0.24082
	5		56.83	1.760	0.24546
	6		56.22	1.779	0.25009
	7		55.63	1.798	0.25472
	8		55.04	1.817	0.25935
	9		54.45	1.836	0.26398
	10		53.88	1.856	0.26861
	11		53.30	1.876	0.27324
	12		52.74	1.896	0.27787
	13		52.18	1.916	0.28251
	14		51.63	1.937	0.28714
	15		51.08	1.958	0.29177
	16		50.54	1.979	0.29640
	17		50.00	2.000	0.30103
	18		49.47	2.021	0.30566
	19		48.94	2.043	0.31029
	20		48.43	2.065	0.31492
	21		47.91	2.087	0.31956
	22		47.40	2.110	0.32419
	23		46.90	2.132	0.32882
3	0		46.40	2.155	0.33345
	1		45.91	2.178	0.33808
	2		45.42	2.201	0.34271
	3		44.94	2.225	0.34734
	4		44.47	2.249	0.35197
	5		43.99	2.273	0.35661
	6		43.53	2.297	0.36124
	7		43.07	2.322	0.36587
	8		42.61	2.347	0.37050
	9		42.16	2.372	0.37513
	10		41.71	2.398	0.37976
	11		41.27	2.423	0.38439
	12		40.83	2.449	0.38902
	13		40.40	2.475	0.39366
	14		39.97	2.502	0.39829
	15		39.54	2.529	0.40292
	16		39.12	2.556	0.40755
	17		38.71	2.583	0.41218
	18		38.30	2.611	0.41681
	19		37.89	2.639	0.42144
	20		37.49	2.667	0.42607
	21		37.09	2.696	0.43071
	22		36.70	2.725	0.43534
	23		36.31	2.754	0.43997
4	0		35.93	2.784	0.44460
	1		35.54	2.813	0.44923
	2		35.17	2.844	0.45386
	3		34.79	2.874	0.45849
	4		34.43	2.905	0.46312
	5		34.06	2.936	0.46776
	6		33.70	2.967	0.47239
	7		33.34	2.999	0.47702
	8		32.99	3.031	0.48165
	9		32.64	3.064	0.48628
	10		32.29	3.097	0.49091
	11		31.95	3.130	0.49554
	12		31.61	3.164	0.50017
	13		31.27	3.197	0.50481
	14		30.94	3.232	0.50944
	15		30.61	3.266	0.51407
	16		30.29	3.301	0.51870
	17		29.97	3.337	0.52333
	18		29.65	3.373	0.52796
	19		29.34	3.409	0.53259
	20		29.03	3.445	0.53722
	21		28.72	3.482	0.54186
	22		28.41	3.520	0.54649
	23		28.11	3.557	0.55112
5	0		27.81	3.595	0.55575
	1		27.52	3.634	0.56038
	2		27.23	3.673	0.56501
	3		26.94	3.712	0.56964
	4		26.65	3.752	0.57427
	5		26.37	3.792	0.57891

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
	6		26.09	3.833	0.58354
	7		25.81	3.874	0.58817
	8		25.54	3.916	0.59280
	9		25.27	3.958	0.59743
	10		25.00	4.000	0.60206
	11		24.73	4.043	0.60669
	12		24.47	4.086	0.61132
	13		24.21	4.130	0.61596
	14		23.96	4.174	0.62059
	15		23.70	4.219	0.62522
	16		23.45	4.264	0.62985
	17		23.20	4.310	0.63448
	18		22.96	4.356	0.63911
	19		22.71	4.403	0.64374
	20		22.47	4.450	0.64837
	21		22.23	4.498	0.65301
	22		22.00	4.546	0.65764
	23		21.76	4.595	0.66227
6	0		21.53	4.644	0.66690
	1		21.30	4.694	0.67153
	2		21.08	4.744	0.67616
	3		20.85	4.795	0.68079
	4		20.63	4.846	0.68542
	5		20.41	4.898	0.69006
	6		20.20	4.951	0.69469
	7		19.98	5.004	0.69932
	8		19.77	5.058	0.70395
	9		19.56	5.112	0.70858
	10		19.35	5.167	0.71321
	11		19.15	5.222	0.71784
	12		18.95	5.278	0.72247
	13		18.75	5.335	0.72711
	14		18.55	5.392	0.73174
	15		18.35	5.450	0.73637
	16		18.16	5.508	0.74100
	17		17.96	5.567	0.74563
	18		17.77	5.627	0.75026
	19		17.58	5.687	0.75489
	20		17.40	5.748	0.75952
	21		17.21	5.810	0.76416
	22		17.03	5.872	0.76879
	23		16.85	5.935	0.77342
7	0		16.67	5.999	0.77805
	6		15.64	6.395	0.80584
	12		14.67	6.817	0.83362
	18		13.76	7.268	0.86141
8	0		12.91	7.748	0.88920
	6		12.11	8.260	0.91699
	12		11.36	8.806	0.94477
	18		10.65	9.388	0.97256
9	0		9.99	10.008	1.00035
	6		9.37	10.669	1.02814
	12		8.79	11.374	1.05592
	18		8.25	12.126	1.08371
10	0		7.74	12.927	1.11150
	12		6.81	14.692	1.16707
11	0		5.99	16.697	1.22265
	12		5.27	18.977	1.27822
12	0		4.64	21.568	1.33380
	12		4.08	24.512	1.38937
13	0		3.59	27.858	1.44495
	12		3.16	31.661	1.50052
14	0		2.78	35.983	1.55610
	12		2.45	40.895	1.61167
15	0		2.15	46.478	1.66725
	12		1.89	52.823	1.72282
16	0		1.67	60.034	1.77840
	12		1.47	68.230	1.83397
17	0		1.29	77.544	1.88955
	12		1.13	88.130	1.94512
18	0		1.00	100.161	2.00070
	12		0.88	113.835	2.05627
19	0		0.77	129.375	2.11185
	12		0.68	147.036	2.16742
20	0		0.60	167.109	2.22300
	12		0.53	189.922	2.27857
21	0		0.46	215.849	2.33415

Mercury-203

half-life 47 d

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
0	0		100.00	1.000	0.00000
	12		99.27	1.007	0.00320
1	0		98.54	1.015	0.00640
	12		97.81	1.022	0.00961
2	0		97.09	1.030	0.01281
	12		96.38	1.038	0.01601
3	0		95.67	1.045	0.01921
	12		94.97	1.053	0.02242
4	0		94.27	1.061	0.02562
	12		93.58	1.069	0.02882
5	0		92.89	1.077	0.03202
	12		92.21	1.084	0.03523

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
6	0		91.53	1.093	0.03843
	12		90.86	1.101	0.04163
7	0		90.19	1.109	0.04483
	12		89.53	1.117	0.04804
8	0		88.87	1.125	0.05124
	12		88.22	1.134	0.05444
9	0		87.57	1.142	0.05764
	12		86.93	1.150	0.06085
10	0		86.29	1.159	0.06405
	12		85.65	1.167	0.06725
11	0		85.02	1.176	0.07045
	12		84.40	1.185	0.07366
12	0		83.78	1.194	0.07686
	12		83.16	1.202	0.08006
13	0		82.55	1.211	0.08326
	12		81.95	1.220	0.08647
14	0		81.35	1.229	0.08967
	12		80.75	1.238	0.09287
15			80.15	1.248	0.09607
16			78.98	1.266	0.10248
17			77.82	1.285	0.10888
18			76.69	1.304	0.11529
19			75.56	1.323	0.12169
20			74.46	1.343	0.12810
21			73.37	1.363	0.13450
22			72.29	1.383	0.14091
23			71.23	1.404	0.14731
24			70.19	1.425	0.15372
25			69.16	1.446	0.16012
26			68.15	1.467	0.16653
27			67.15	1.489	0.17293
28			66.17	1.511	0.17934
29			65.20	1.534	0.18574
30			64.25	1.556	0.19215
31			63.31	1.580	0.19855
32			62.38	1.603	0.20496
33			61.47	1.627	0.21136
34			60.57	1.651	0.21777
35			59.68	1.676	0.22417
36			58.81	1.701	0.23058
37			57.95	1.726	0.23698
38			57.10	1.751	0.24339
39			56.26	1.777	0.24979
40			55.44	1.804	0.25620
41			54.63	1.831	0.26260
42			53.83	1.858	0.26901
43			53.04	1.885	0.27541
44			52.26	1.913	0.28182
45			51.50	1.942	0.28822
46			50.74	1.971	0.29463
47			50.00	2.000	0.30103
48			49.27	2.030	0.30744
49			48.55	2.060	0.31384
50			47.84	2.090	0.32025
51			47.14	2.122	0.32665
52			46.45	2.153	0.33306
53			45.77	2.185	0.33946
54			45.10	2.218	0.34587
55			44.44	2.250	0.35227
56			43.78	2.284	0.35868
57			43.14	2.318	0.36508
58			42.51	2.352	0.37149
59			41.89	2.387	0.37789
60			41.28	2.423	0.38430
62			40.08	2.495	0.39710
64			38.91	2.570	0.40991
66			37.78	2.647	0.42272
68			36.68	2.726	0.43553
70			35.62	2.808	0.44834
72			34.58	2.892	0.46115
74			33.58	2.978	0.47396
76			32.60	3.067	0.48677
78			31.65	3.159	0.49958
80			30.73	3.254	0.51239
82			29.84	3.351	0.52520
84			28.97	3.452	0.53801
86			28.13	3.555	0.55082
88			27.31	3.661	0.56363
90			26.52	3.771	0.57644
92			25.75	3.884	0.58925
94			25.00	4.000	0.60206
96			24.27	4.120	0.61487
98			23.57	4.243	0.62768
100			22.88	4.370	0.64049
102			22.22	4.501	0.65330
104			21.57	4.636	0.66611
106			20.94	4.774	0.67892
108			20.34	4.917	0.69173
110			19.75	5.065	0.70454
112			19.17	5.216	0.71735
114			18.61	5.372	0.73016
116			18.07	5.533	0.74297
118			17.55	5.699	0.75578
120			17.04	5.869	0.76859
122			16.54	6.045	0.78140
124			16.06	6.226	0.79421

d	h	min	N_t	N_0/N_t	$\log_{10} N_0/N_t$
126			15.59	6.412	0.80
128			15.14	6.604	0.81
130			14.70	6.802	0.83
132			14.27	7.006	0.84
134			13.86	7.215	0.85
136			13.46	7.431	0.87
138			13.07	7.654	0.88
140			12.69	7.883	0.89
145			11.78	8.486	0.92
150			10.95	9.136	0.96
155			10.17	9.835	0.99
160			9.45	10.587	1.02
165			8.77	11.398	1.05
170			8.15	12.270	1.08
175			7.57	13.209	1.12
180			7.03	14.220	1.15
185			6.53	15.308	1.18
190			6.07	16.479	1.21
195			5.64	17.740	1.24
200			5.24	19.098	1.28
205			4.86	20.559	1.31
210			4.52	22.133	1.34
215			4.20	23.826	1.377
220			3.90	25.650	1.409
225			3.62	27.613	1.441
230			3.36	29.726	1.473
235			3.12	32.000	1.505
240			2.90	34.449	1.537
245			2.70	37.086	1.569
250			2.50	39.924	1.601
255			2.33	42.979	1.633
260			2.16	46.268	1.665
265			2.01	49.809	1.697
270			1.86	53.620	1.729
275			1.73	57.724	1.761
280			1.61	62.141	1.793
285			1.49	66.896	1.825
290			1.39	72.016	1.857
295			1.29	77.527	1.889
300			1.20	83.460	1.9214
305			1.11	89.846	1.9535
310			1.03	96.722	1.9855
315			0.96	104.124	2.0175
320			0.89	112.092	2.0495
325			0.83	120.670	2.0816
330			0.77	129.904	2.1136
335			0.72	139.845	2.1456
340			0.66	150.547	2.1776
345			0.62	162.068	2.2097
350			0.57	174.470	2.2417
355			0.53	187.822	2.2737
360			0.49	202.195	2.3057

(For references see page 312)

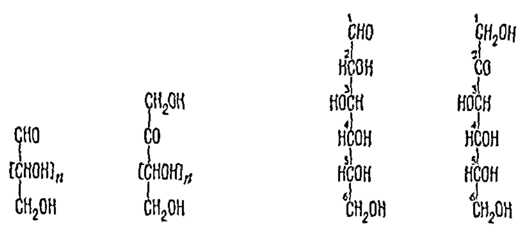
Carbohydrates [1]

Carbohydrates are carbon compounds containing hydrogen and oxygen in the ratio 2:1, their general empirical formula being $C_x(H_2O)_y$**. The term is also extended, however, to oxidation and reduction products of carbohydrates proper, as well as to their simple derivatives such as amino and phosphorylated sugars.

Carbohydrates are frequently referred to as 'sugars' (saccharides) because many of them possess a sweet taste*** but actually the term 'sugar' is only loosely defined and may denote a wide variety of carbohydrate compounds. To the carbohydrate chemist, however, it means a mono- or oligosaccharide but *not* a polysaccharide (see below). Mono- and oligosaccharides are given names with the suffix '-ose', e.g., glucose, fructose, lactose.

Monosaccharides

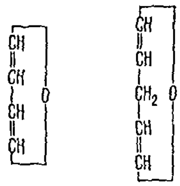
Carbohydrates that cannot be split further by hydrolysis are called simple sugars or monosaccharides. Their general empirical formula is $[C(H_2O)]_n$ and they are classed as aldehydic alcohols (aldoses) or ketonic alcohols (ketoses). Those of importance to mammals are listed in Table 1 (pages 313–316).



Aldose Ketose Glucose Fructose

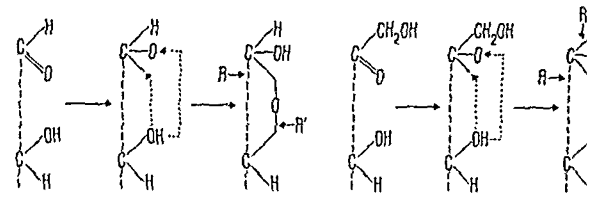
Sugars with chain lengths of 3, 4, 5, 6, etc. carbon atoms are known as trioses, tetroses, pentoses, hexoses, etc.†. The numbering convention is shown above in the structures of glucose and fructose.

The *open-chain form of sugars (aldehyde or ketone form)* normally occurs only in aqueous solution, where it is a transitional form in equilibrium with the ring form. The latter is the rule with carbohydrates of longer chain length, and with few exceptions the ring is usually 5- or 6-membered. By analogy with the similar heterocyclic compounds†† furan and pyran, these ring forms are known as *furanoses* and *pyranoses* respectively:



Furan Pyran

The ring forms are formed from chain forms by the reaction of the hydroxyl group in the 4 or 5 position with the carbonyl group. Carbon atom 4 is involved in the case of furanoses, carbon atom 5 in the case of pyranoses. This results in the formation of an oxygen bridge between the carbon atoms concerned and of a hydroxyl group on the carbon atom of the original carbonyl group:

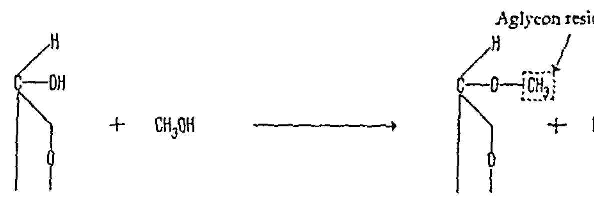


Chain form (aldoses) Ring form Chain form (ketoses) Ring f

The compound formed is an intramolecular hemiacetal (w derived from an aldose) or hemiketal (when derived from a ketc

Acetal Hemiacetal Ketal Hemiketal

The hydroxyl group attached to the hemiacetal or hemike carbon atom (C-1 or C-2 respectively) is particularly reactive anc known as the glycosidic hydroxyl. It combines readily with t alcoholic or phenolic groups of other molecules, and when tl reaction takes place with a compound that is not another sug (an aglycon), the resulting compound is known as a *glycoside*:



Sugar Aglycon (here methanol) Glycoside (methylglycosid

When the reaction takes place with a molecule of another sug the resulting compound is known not as a glycoside but as a di saccharide (cf. 'Oligo- and Polysaccharides', page 312).

Stereochemistry of sugars

The stereoisomerism of sugars and related substances is o particular importance in biochemistry*, and for this reason it wil be dealt with in some detail here. For a more thorough treatmen of the subject see HONEYMAN[2]. A carbon atom with four differen substituents, for example C-2 of glyceraldehyde, is known as ar *asymmetric* carbon atom. This grouping cannot be superimposed or its mirror image and the resulting lack of symmetry gives rise to a type of isomerism associated with optical activity. The two possible spatial configurations of the substituents can be readily seen if one imagines the asymmetric C atom to be in the middle of a regular tetrahedron with the valencies pointing to the corners. The two possible configurations of glyceraldehyde shown as an example in Figure 1 cannot in any way be superimposed one upon the other. They are related to one another as an object to its mirror image, and are known as enantiomorphs. No such asymmetry exists with a carbon atom possessing at least two identical substituents.

Enantiomorphic isomers are optically active, i.e., in solution one of the isomers rotates the plane of polarized light to the right, the other an equal amount to the left. The degree of rotation depends on the length of the polarimeter tube, on the wave length of the polarized light, on the concentration, and on the solvent and its temperature**. The direction of rotation was originally indicated by prefixing the name of the isomer by *dextro (d-)* and *laevo (l-)*

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* This chapter, 'Constituents of Living Matter', has been written in consul- tat … of … istry, … versity of British Columbia), J.R. QUAYLE (Department of Microbiology, University of Sheffield, England), J.M. LOWENSTEIN (Graduate Department of Biochemistry, Brandeis University, Waltham, Mass., USA) and P.R. RAGGATT (Department of Biochemistry, University of Oxford, England).

** There are compounds with this empirical formula that do not fall into the category of carbohydrates, such as acetic acid, lactic acid, phloroglucinol.

*** The sweetest of the sugars is fructose. Polysaccharides have no taste.

† According to BEILSTEIN (1938) these names are derived from the number of oxygen atoms. In the case of 'ordinary' monosaccharides $[C(H_2O)]_n$ both nomenclatures are identical. They are different in the case of substituted and deoxy sugars. In general the nomenclature based on the number of carbon atoms is the more commonly used and permits a better understanding of carbohydrate metabolism (anabolism of the carbon chain from small molecules and its subsequent catabolism).

†† Heterocycles are ring molecules in which apart from carbon atoms the ring contains at least one atom of another element.

* Stereoisomerism is of importance in nature not only for carbohydrates but for all compounds where stereoisomers are possible. This is because as a rule only specific stereoisomers are synthesized or degraded in naturally occurring reactions (this is a characteristic difference compared to laboratory synthesis). One reason is the stereospecificity of many enzymes, but the fundamental mechanism is unknown.

** The specific rotation [α] is defined as the rotation in degrees of 1g of substance in 1ml of solution in a tube with a length of 10 cm. The D-line of sodium is as a rule used as a source of light. The temperature, wave length of the incident light, nature of the solvent and the concentration must also be included where these diverge from the definition, e.g., $[\alpha]_D^{20°}$, 20% (H_2O) = +12°.

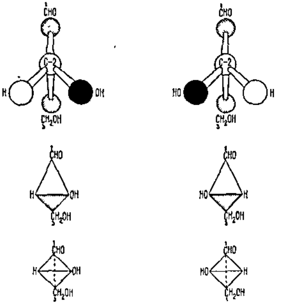
(For references see page 312)

Fig 1 Stereoisomerism of glyceraldehyde

I

II

III



I Atomic models

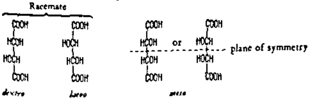
II Tetrahedral representation of I The edge of the tetrahedron joining C-1 and C-3 (imagined to be in or below the plane of the paper) is invisible, as is also the asymmetric carbon atom C 2 lying inside the tetrahedron

III Conventional representation of the tetrahedron The edge between C-1 and C-3 in the plane of the paper is indicated by a broken line the other edges (all above the plane of the paper) by full lines

respectively. The alternative symbols (+) and (−) are now more commonly used*.

A racemate must not be confused with an optically inactive *meso* form. A *meso* form may arise in the case of a molecule possessing more than one asymmetric centre where the configuration is such that there is a plane or centre of symmetry in the molecule as a whole The various directions of rotation then cancel each other out within the molecule (internal compensation) These racemic and meso forms are illustrated by the cases of tartaric acid and hexahydrohexahydroxybenzene

Isomers of tartaric acid

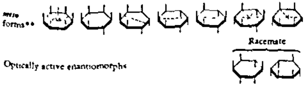


(mirror image forms) (identical forms, as can be seen by turning one through 180° in the plane of the paper)

Isomers of hexahydrohexahydroxybenzene (inositol)

meso forms**

Optically active enantiomorphs



(The vertical lines indicate the positions of the OH groups, the broken lines the planes of symmetry)

* The use of the letters *d* and *l* to denote optical rotation is now discouraged in favour of *dextro* and *laevo*, or better (+) and (−). DL is likewise preferred for racemates

** Although all structures are *meso* forms and optically inactive, the name mesoinositol is confined to the fifth compound from the left

Meso forms do not occur in the case of sugars since the carbo group on one side of the ring renders meso-symmetry impossi

The classification of carbohydrate molecules is based on t relationship to the simplest optically active sugar, glyceraldeh to which ROSANOFF[3] arbitrarily assigned the following c figurations·

Projection formulae (FISCHER)

Dextrorotatory glyceraldehyde

Laevorotatory glyceraldehyde

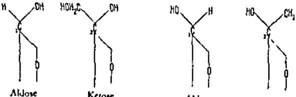
(With the carbonyl group at the top, the hydroxyl group is written on right of the asymmetric carbon atom in the case of the dextrorotatory c pound, and on the left in the case of the laevorotatory compound)

the parent substance can increase or decrease or even be rever

methods

With a few exceptions, all naturally occurring sugars belong

group, thus introducing an additional asymmetric centre. The t stereoisomers of a cyclic sugar molecule arising in this way a denoted by the symbols α and β (after HUDSON[4]), the designati α being given to the isomer in the D-series that is more strong *dextro*rotatory and to the isomer in the L-series that is mo



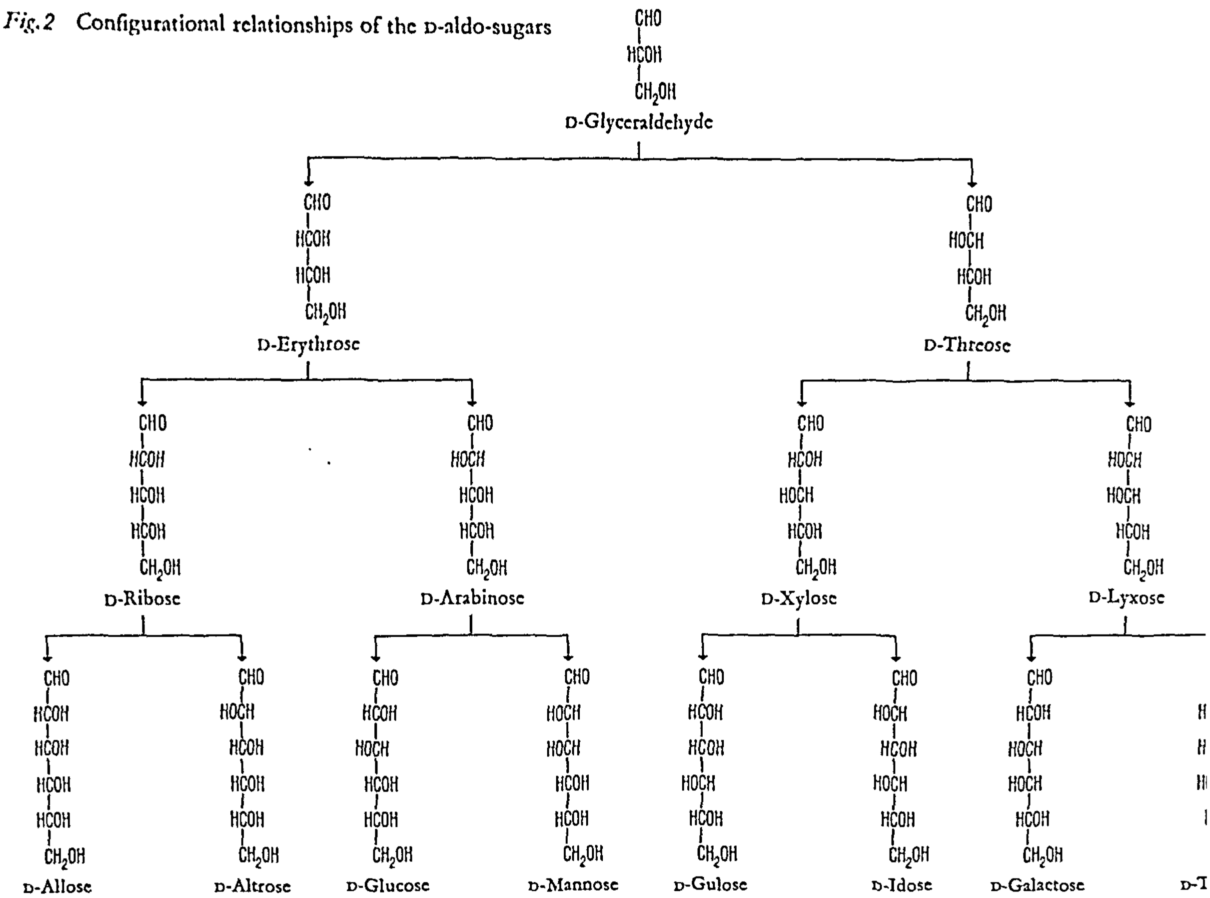
α D or β L

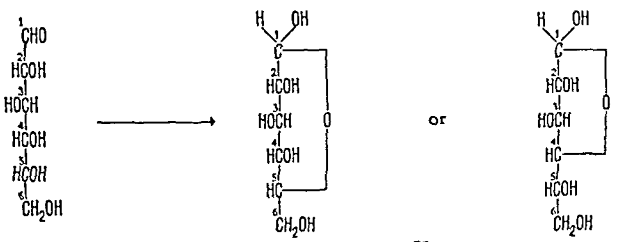
β D or α L

The α- and β-isomers yield

(For references see page 312)

Fig. 2 Configurational relationships of the D-aldo-sugars

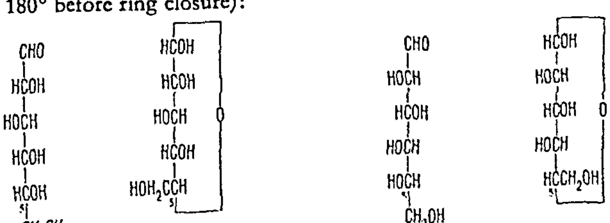




I D-Glucose — II α-D-Glucopyranose or α-D-Glucofuranose

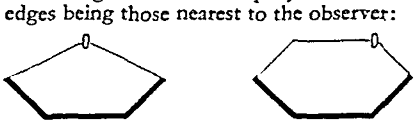
The ring formulae of type II are commonly used because their relationship to the chain formula I can readily be seen. However, although the steric relations of the secondary alcohol groups (–CHOH) forming the ring are correctly represented by these formulae, they do not give a true picture of the steric configuration around the C atom to which the oxygen bridge is attached (C-5 in the case of glucopyranose, C-4 in the case of glucofuranose). This arises from the fact that it is the convention, as described above, to write this group in the chain formulae of the D-series with the OH group on the right.

In the case of the pyranoses, a more correct type of projection formula is that illustrated by III and IV for glucose (derived by imagining the bond between C-4 and C-5 to be rotated through 180° before ring closure):



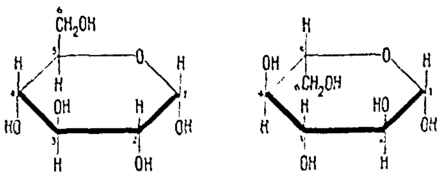
D-Glucose — III α-D-Gluco-pyranose — L-Glucose — IV β-L-Gluco-pyranose

In formulae III and IV, however, the D- and L-configurations respectively of the OH group attached to C-5 are no longer readily recognizable. These defects of the FISCHER projection for led HAWORTH to introduce a type of ring formula in whi steric relations of the groups are shown unequivocally. Th is imagined as being looked at obliquely from above, the thickened edges being those nearest to the observer:



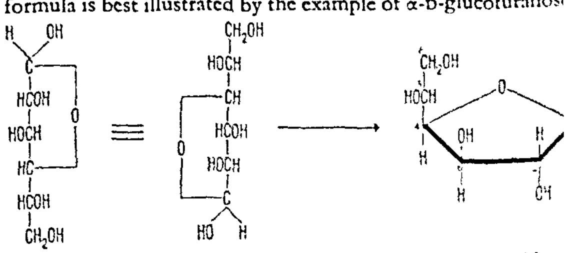
Furanose ring — Pyranose ring

The positions of the substituents correspond to those ir mulae of type III and IV:



α-D-Glucopyranose — β-L-Glucopyranose

In the case of the furanose forms of hexoses, ring closure re in the formation of a side chain. When, as in the case of gl furanose, this side chain contains an asymmetric carbon atom configuration in the HAWORTH formula must be shown by m of an appropriate convention. The derivation from the projec formula is best illustrated by the example of α-D-glucofuranos

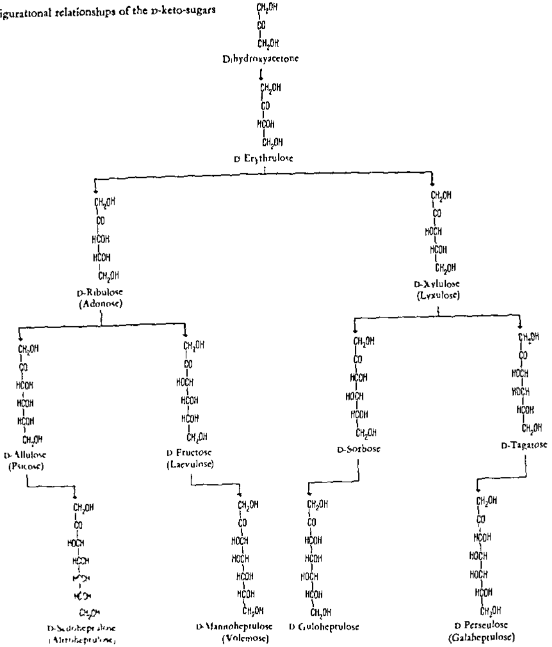


For convenience in writing the formulae of polysaccharides : other complex sugar compounds, the HAWORTH rings are so

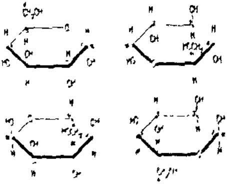
Constituents of Living Matter – Carbohydrates

(For references see page 312)

Configurational relationships of the D-keto-sugars



native positions for α-D-glucopyranose are as follows



It is now known that the pyranose ring is not planar, of its properties can be explained on the assumption that 'chair' form. The furanose ring is usually planar. For furt of the conformational analysis see the literature[6]

Amino sugars[7]

Amino sugars are components of polysaccharides (see l

d antibiotics[8].

Sugar phosphates[10]

Phosphorylated sugars are intermediates in glycolysis; they are components of nucleic acids, nucleotides and polysaccharides[11] (see Table 2, pages 317–321).

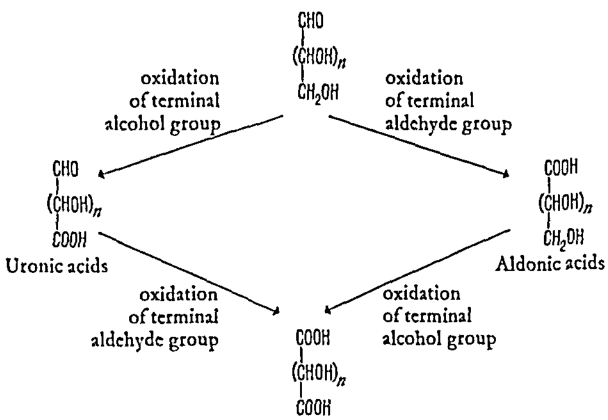
The stability of phosphate groups toward acid or alkaline hydrolysis varies over a wide range[12] and, as yet, detailed correlation between the rates of hydrolysis and the position of the groups has not been made. Under conditions of acid or alkaline hydrolysis, migration of the phosphate group may occur, e.g., in the case of the phosphoglyceric acids[13].

Polyhydric alcohols[14]

These compounds, which may be considered as reduction products of the monosaccharides, are of wide occurrence in plants but of limited occurrence in mammalian tissue. They are mostly crystalline compounds, generally possessing a sweet taste and devoid of any reducing properties. Those of importance to mammals are listed in Table 3 (page 322).

Primary oxidation products of carbohydrates

The nomenclature of the products of the oxidation of the terminal groups of aldoses is derived as follows:

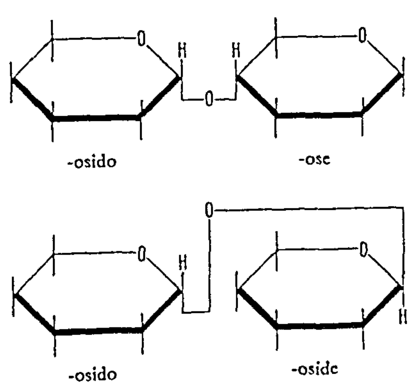


Saccharic acids (aric acids)

Oxidation products of carbohydrates of importance to mammals are listed in Table 4 (page 323).

Oligosaccharides

Oligosaccharides are composed of monosaccharide molecules or their derivatives linked together through glycosidic linkages. The linkages may be glycosidic on one side only or on both sides. In the nomenclature of oligosaccharides, the sugar units in compounds of the former type are given the suffixes '-osido' and '-ose', while those in the latter type are indicated by '-osido' and '-oside'. This is illustrated by the following scheme:



The term oligosaccharide is generally used to designate compou containing between two and ten monosaccharide units per m cule. Oligosaccharides may be reducing or nonreducing, depe ing on the presence or absence of free hemiacetal hydroxyl grou The constituent monosaccharides are set free from an oli saccharide by acid or enzymic hydrolysis.

The principal oligosaccharides of importance to mammals given in Table 5 (page 324). A great variety of oligosaccharide encountered in the plant kingdom.

Polysaccharides[15]

Polysaccharides, like oligosaccharides, are built up fron variety of monosaccharide units and their derivatives. They di from oligosaccharides in that their molecules contain from ten to several thousand monosaccharide units. The most commonly curring constituent is D-glucose. However, D-mannose, D- and L- lactose, D-xylose, L-arabinose, uronic acids (D-glucuronic, D-gal turonic and D-mannuronic acids), amino sugars (D-glucosami D-galactosamine, their N-acetyl derivatives and sulphate esters) also found. In contrast with the oligosaccharides many of the po saccharides are insoluble and nonreducing.

Their structure has been investigated by chemical methods e.g., by methylation and subsequent hydrolysis, by periodate o dation, and by enzymic methods[16]. The determination of t molecular size of polysaccharides involves physical measureme of properties such as osmotic pressure, behaviour on ultracent fuging, viscosity and light scattering[17].

Polysaccharides may serve as:

(a) structural materials, e.g., cellulose (plants), chitin (insects ar crustaceae), chondroitin sulphate (cartilage)[18],
(b) food storage, e.g., glycogen (animals), starch (plants),
(c) lubricants in synovial fluids, constituents of special tissues (vitr ous body of the eye; connective tissue), components of mucu heparin, blood-group substances[18].

The principal polysaccharides of importance to mammals ar listed in Table 6 (pages 325–328).

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12 See LELOIR, L.F., in ZECHMEISTER, L. (Ed.), *Progress in the Chemistry of Organic Natural Products*, vol. 8, Springer, Vienna, 1951, page 47.
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18 Cf. KENT and WHITEHOUSE, *Biochemistry of the Aminosugars*, Butterworth, ... HANG, G., in ZECH- ... ural Products, vol. 20,

Constituents of Living Matter – Carbohydrates

ble 1 Monosaccharides of importance to mammals

Some of the more important sugars that are constituents of substances of medical interest are also included in this table

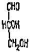
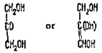
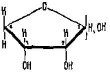
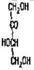
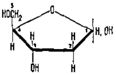
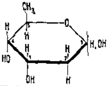
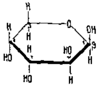
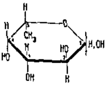
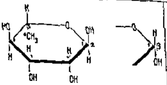
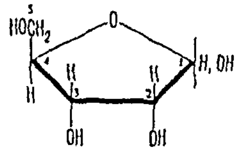
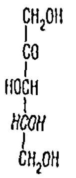
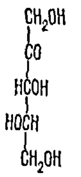
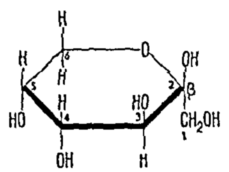
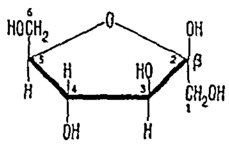
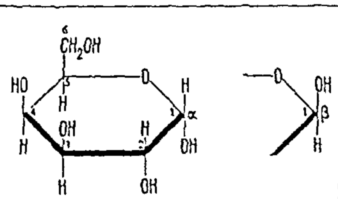
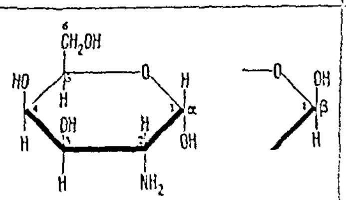
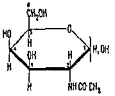
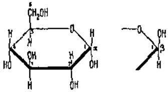
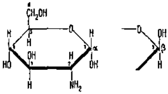
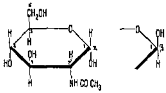
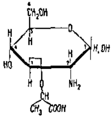
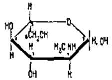
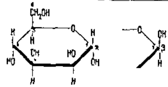
Name	Formula and mol wt.	Structure	Specific rotation	Occurrence
		Trioses		
-Glyceraldehyde (2,3-dihydroxy-propanal)	$C_3H_6O_3$ 90 08		$[\alpha]_D^{20}$ + 13.5°	As phosphate ester (see T 2, page 317)
-Dihydroxyacetone (1,3-dihydroxy-propan-2-one)	$C_3H_6O_3$ 90 08		Inactive	As phosphate ester (see T 2, page 317)
		Tetroses		
D-Erythrose	$C_4H_8O_4$ 120 11		$[\alpha]_D^{20}$ − 14 8°	As phosphate ester (see T 2, page 317)
L-Erythrulose	$C_4H_8O_4$ 120 11		$[\alpha]_D^{20}$ + 12°	As metabolically active p phate ester (see Table 2, 317)
2-Deoxy-D-ribose (2-deoxy-D-*erythro*pentose, thyminose, deoxyarabinose)	$C_5H_{10}O_4$ 134 13		$[\alpha]_D^{18}$ − 50°	Universal occurrence as stituent of nucleosides, cleotides and nucleic a For phosphates see Tab page 318
D-Digitoxose (2-deoxy-D-*altro*methylose)	$C_6H_{12}O_4$ 148 16		$[\alpha]_D^{20}$ + 46 5°	Component of digitalis g sides
		Pentoses		
β-D-Arabinose	$C_5H_{10}O_5$ 150 13		$[\alpha]_D^{20}$ − 105°	In glycosides of aloe an bercle bacilli
L-Fucose (6-deoxy-L-galactose)	$C_6H_{12}O_5$ 164 16		$[\alpha]_D^{20}$ − 153° → + 76°	Component of polysa rides of human milk, b group substances, marin gae, gum tragacanth Table 5, page 324)
L-Rhamnose (6-deoxy-L-mannose, isodulcitol)	$C_6H_{12}O_5$ 164 16		α-form, 1 H_2O $[\alpha]_D^{20}$ − 9° β-form, $[\alpha]_D^{20}$ + 38°	As glycoside in plant ments, gums and mucil Common component of ac glycosides

Table 1 (continued) Monosaccharides of importance to mammals

Name*	Formula and mol. wt.	Structure	Specific rotation	Occurrence
D-Ribose (Rib) (D-ribofuranose)	$C_5H_{10}O_5$ 150.13		$[\alpha]_D^{20}$ – 23.7° (4% soln.)	Universal occurrence as constituent of nucleosides, nucleotides and nucleic acids. For phosphates see Table 2, pages 317–318
D-Ribulose (D-*erythro*pentulose, D-adonose, D-arabulose)	$C_5H_{10}O_5$ 150.13		–	As phosphate esters (see Table 2, page 318). Intermediary metabolite in glucose oxidation
D-Xylulose (D-*threo*pentulose, D-xyloketose, D-lyxulose, D-lyxoketose)	$C_5H_{10}O_5$ 150.13		$[\alpha]_D^{20}$ – 33°	As phosphate ester (see Table 2, page 318)
L-Xylulose (L-*threo*pentulose, L-xyloketose, L-lyxulose, L-lyxoketose)	$C_5H_{10}O_5$ 150.13		$[\alpha]_D^{20}$ + 33°	In urine in pentosuria
		Hexoses		
D-Fructose (Fru) (2-keto-D-arabohexose, laevulose, fruit sugar)	$C_6H_{12}O_6$ 180.16	 β-D-Fructopyranose  β-D-Fructofuranose	β-form: $[\alpha]_D^{20}$ – 133.5° → – 92°	As phosphate esters (see Table 2, pages 318–319). Component of many polysaccharides (combined with glucose in sucrose). Has pyranose form when crystalline but furanose form in all natural products. Sweetest of all known sugars
D-Galactose (Gal) (cerebrose, brain sugar)	$C_6H_{12}O_6$ 180.16		α-form: $[\alpha]_D^{20}$ + 144° → + 80.5° β-form: $[\alpha]_D^{20}$ + 54° → + 80.5°	Present in mammalian tissues as phosphate ester (see Table 2, page 319). Component of cerebrosides and gangliosides, and of polysaccharides both as sugar and derived amino sugar (e.g., lactose, raffinose, stachyose)
D-Galactosamine (GalN) (D-chondrosamine, 2-amino-2-deoxy-D-galactose)	$C_6H_{13}NO_5$ 179.17		α-form, 1 HCl: $[\alpha]_D^{20}$ + 135° → + 93° β-form, 1 HCl: $[\alpha]_D^{20}$ + 39° → + 93°	Widely distributed in nature as component of hyaluronic acid, mucopolysaccharides, cartilage, tendons (chondroitin), β-heparin, lipoids, cerebral gangliosides, blood-group substances, glycoproteins (see Table 6, pages 326–328)

* The three-letter symbols are those recommended by the Combined Commission on *Biochemical Nomenclature* of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry (*J. Biol. Chem.*, **241**, 527 [1966]).

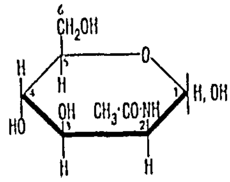
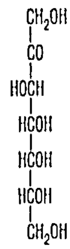
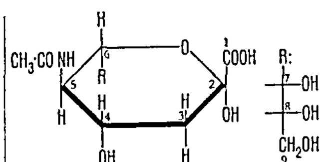
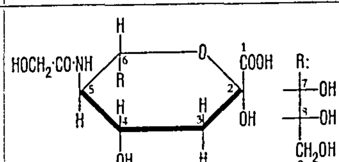
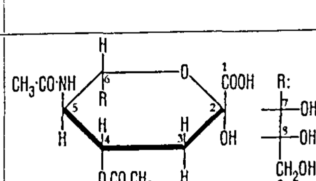
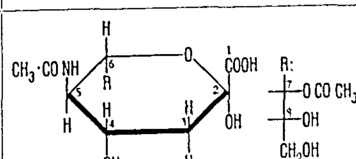
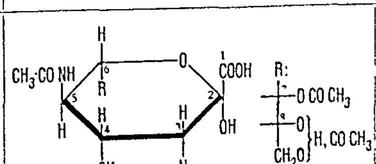
Table 1 (continued) Monosaccharides of importance to mammals

Name*	Formula and mol wt.	Structure	Specific rotation	Occurrence
N-Acetyl-D-galactosamine	$C_8H_{15}NO_6$ 221 21		$[\alpha]_D^{20}$ + 115° → + 80°	Form in which D-galactosamine (page 314) occurs as component of hyaluronic acid, etc.
D-Glucose (Glc, G) (dextrose, blood sugar, grape sugar, corn sugar)	$C_6H_{12}O_6$ 180 16		α-form: $[\alpha]_D^{20}$ + 113 4° → + 52 5° β-form: $[\alpha]_D^{20}$ + 19 3° → + 52 5°	As phosphate esters (see Table 2, page 319) Most widely distributed of all sugars Found free in many biological fluids, e g, blood, lymph, cerebrospinal fluid Component of polysaccharides both as sugar and amino sugar (see 'D-Glucosamine', below)
D-Glucosamine (GlcN) (chitosamine, 2-amino-2-deoxy-D-glucose)	$C_6H_{13}NO_5$ 179 17		α-form $[\alpha]_D^{20}$ + 100° – β-form $[\alpha]_D^{20}$ + 14° →	[illegible]
N-Acetyl-D-glucosamine	$C_8H_{15}NO_6$ 221 21		–	Form in which D glucosamine occurs as component of chitin, etc
3 O-Carbethoxyglucosamine (muramic acid)	$C_9H_{17}NO_7$ 251 24		$[\alpha]_D^{20}$ + 109° (water)	Component of bacterial cell walls†
N Methyl-L glucosamine	$C_7H_{15}NO_5$ 193 20		–	Component of streptomycin
D-Mannose (Man) (seminose)	$C_6H_{12}O_6$ 180 16		α form $[\alpha]_D^{20}$ + 29 9° → + 14 5° β-form $[\alpha]_D^{20}$ – 16 3° → + 14 5°	As phosphate ester (see Table 2, page 320) Widely distributed as component of mannans and hemicelluloses Limited occurrence as component of glycoproteins

* See footnote, page 314

† ROGERS H J, *Biochem Soc Symp*, No 22, 55 (1963)

Table 1 (concluded) Monosaccharides of importance to mammals

Name	Formula and mol. wt.	Structure	Specific rotation	Occurrence
N-Acetyl-D-mannosamine	$C_8H_{15}NO_6$ 221.21		$[\alpha]_D^{20}$ − 9.4°→ + 9.7°	Intermediate in biosynt of *N*-acetylneuraminic ac
		Heptose		
D-Sedoheptulose (D-*altro*ketoheptose, D-*altro*heptulose)	$C_7H_{14}O_7$ 210.19		$[\alpha]_D^{20}$ + 2–3° Ba salt: $[\alpha]_{5461}^{20}$ + 8°	As phosphate esters (see T 2, page 321)
		Nonoses		
N-Acetylneuraminic acid	$C_{11}H_{19}NO_9$ 309.28		$[\alpha]_D^{22}$ − 32° No mutarotation	Component of mucins of e thelial secretions (e.g., dig tive and urinary tracts), ser glycoproteins, milk oligos charides, brain gangliosid erythrocyte stroma, bacte cell walls
N-Glycolylneuraminic acid	$C_{11}H_{19}NO_{10}$ 325.27		$[\alpha]_D^{22}$ − 32°	Component of mucins of e thelial secretions, serum gly proteins, erythrocyte stro Often in the same molecule *N*-acetylneuraminic acid
5-*N*,4-*O*-Diacetyl-neuraminic acid	$C_{13}H_{21}NO_{10}$ 351.31		$[\alpha]_D^{22}$ − 61° No mutarotation	Equine submaxillary mucin
5-*N*,7-*O*-Diacetyl-neuraminic acid	$C_{13}H_{21}NO_{10}$ 351.31		$[\alpha]_D^{22}$ + 8° After 400 h − 17°	Bovine submaxillary mucin
5-*N*-Acetyl,*O*-diacetyl-neuraminic acid	$C_{15}H_{23}NO_{11}$ 393.35		$[\alpha]_D^{22}$ + 9°	Bovine submaxillary mucin

Sugar phosphates of importance to mammals
(Not including nucleotides, for which see Tables 10c, 11 and 12, pages 342–350)

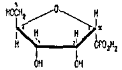
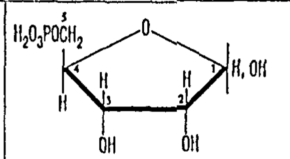
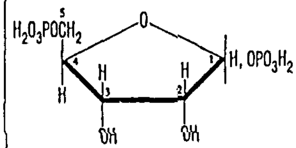
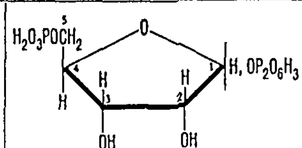
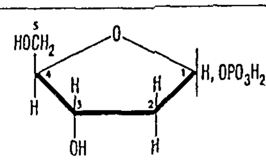
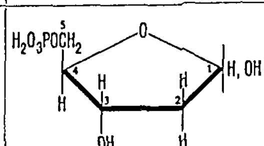
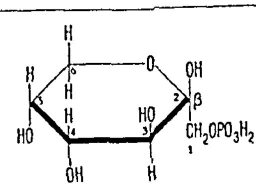
Name	Formula and mol. wt.	Structure	Elementary composition C	H	P	Specific rotation	Biological function	Reference (see page 321)
lroxyacetone ›sphate	$C_3H_7O_6P$ 170 06	CH_2OH–CO–$CH_2OPO_3H_2$	21 19	4 15	18 21	–	Intermediate of glycolysis	1
'ceraldehyde hosphate ISCHER-BAER :r')	$C_3H_7O_6P$ 170 06	CHO–HCOH–$CH_2OPO_3H_2$	21.19	4 15	18 21	$[\alpha]_D^{20}$ + 14°	Intermediate of glycolysis	2
'cerol ›hosphate	$C_3H_9O_6P$ 172 08	$CH_2OPO_3H_2$–HOCH–CH_2OH	20 94	5 27	18 00	$[\alpha]_D^{20}$ − 1 45° (Ba salt)	Intermediate of fat metabolism Component of phospholipids	3
yceric acid ›hosphate :IESSLING ester')	$C_3H_7O_7P$ 186 06	COOH–$HCOPO_3H_2$–CH_2OH	19 37	3 79	16 65	$[\alpha]_D^{20}$ + 13° (1-N HCl) $[\alpha]_D^{18}$ + 3 6° (water)	Intermediate of glycolysis	4
yceric acid phosphate	$C_3H_7O_7P$ 186 06	COOH–HCOH–$CH_2OPO_3H_2$	19 37	3 79	16 65	$[\alpha]_D^{20}$ − 14 5° (1-N HCl)	Intermediate of glycolysis	5
yceric acid ›-diphosphate	$C_3H_8O_{10}P_2$ 266 04	$COOPO_3H_2$–HCOH–$CH_2OPO_3H_2$	13 54	3 03	23 29	$[\alpha]_D^{20}$ − 2 3°	Intermediate of glycolysis	6
yceric acid 3-diphosphate	$C_3H_8O_{10}P_2$ 266 04	COOH–$HCOPO_3H_2$–$CH_2OPO_3H_2$	13 54	3 03	23 29	$[\alpha]_D^{26}$ − 2 3°	Intermediate of glycolysis	7
ıvic acid enol ıosphate ›hosphopyruvic ›id)	$C_3H_5O_6P$ 168 04	COOH–$COPO_3H_2$=CH_2	21 44	3 00	18 43	–	Intermediate of glycolysis	8
rythrose phosphate	$C_4H_9O_7P$ 200 09	CHO–HCOH–HCOH–$CH_2OPO_3H_2$	24 01	4 53	15 48	–	Intermediate of pentose phosphate cycle	9
rythrulose -phosphate	$C_4H_9O_7P$ 200 09	$CH_2OPO_3H_2$–CO–HOCH–CH_2OH	24 01	4 53	15 48	–	Function not known	10
-Ribose -phosphate furanose form)	$C_5H_{11}O_8P$ 230 11		26 10	4 82	13 46	–	Intermediate of nucleotide metabolism	11

Table 2 (continued) Sugar phosphates of importance to mammals

Name	Formula and mol. wt.	Structure	Elementary composition C	Elementary composition H	Elementary composition P	Specific rotation	Biological function	
D-Ribose 5-phosphate (furanose form)	$C_5H_{11}O_8P$ 230.11		26.10	4.82	13.46	$[\alpha]_D^{20}$ + 16.5°	Intermediate of pentose phosphate cycle and nucleotide synthesis	
D-Ribose 1,5-diphosphate (furanose form)	$C_5H_{12}O_{11}P_2$ 310.09		19.37	3.90	19.98	–	Intermediate of interconversion of ribose 1-phosphate and ribose 5-phosphate	
D-Ribose 5-phosphate-1-pyrophosphate (5-phosphoribosyl-1-pyrophosphate)	$C_5H_{13}O_{14}P_3$ 390.07		15.40	3.36	23.82	–	Intermediate of nucleotide synthesis	
Deoxyribose 1-phosphate (furanose form)	$C_5H_{11}O_7P$ 214.11		28.05	5.18	14.47	–	Product of nucleoside degradation	15
Deoxyribose 5-phosphate (furanose form)	$C_5H_{11}O_7P$ 214.11		28.05	5.18	14.47	–	Component of deoxynucleic acids and deoxynucleotides	16
D-Ribulose 5-phosphate	$C_5H_{11}O_8P$ 230.11	CH_2OH CO HCOH HCOH $CH_2OPO_3H_2$	26.10	4.82	13.46	$[\alpha]_D^{20}$ – 40°	Intermediate of pentose phosphate cycle	17
D-Xylulose 5-phosphate	$C_5H_{11}O_8P$ 230.11	CH_2OH CO HOCH HCOH $CH_2OPO_3H_2$	26.10	4.82	13.46	–	Intermediate of pentose phosphate cycle	18
D-Fructose 1-phosphate (pyranose form) ('ROBISON-TANKO ester')	$C_6H_{13}O_9P$ 260.14		27.70	5.04	11.91	$[\alpha]_D^{24}$ – 30.4°	Intermediate of glycolysis	19

2 (continued) Sugar phosphates of importance to mammals

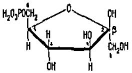
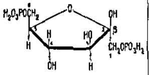
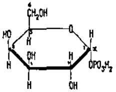
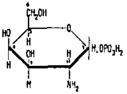
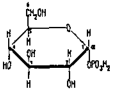
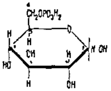
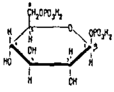
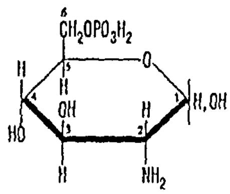
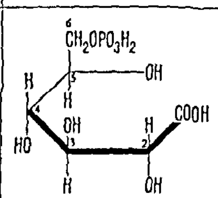
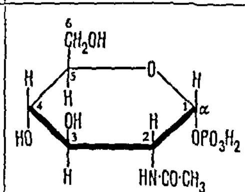
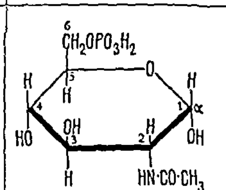
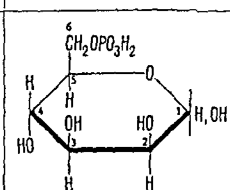
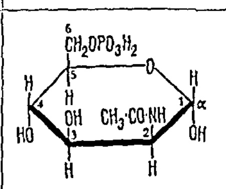
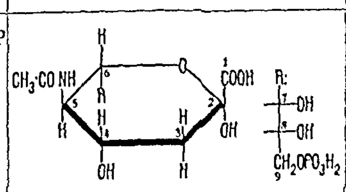
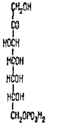
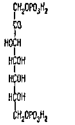
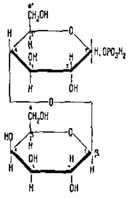
Name	Formula and mol wt.	Structure	Elementary composition			Specific rotation	Biological function	Reference (see page 321)
			C	H	P			
uctose phosphate uranose form) NEUBERG ester')	$C_6H_{13}O_9P$ 260 14		27.70	5 04	11.91	$[\alpha]_D^{18}$ + 3.58° (Ba salt)	Intermediate of glycolysis	20
ructose 6-diphosphate uranose form) HARDEN-YOUNG ster')	$C_6H_{14}O_{12}P_2$ 340 12		21 19	4 15	18 21	$[\alpha]_D^{17}$ + 4 1°	Intermediate of glycolysis	21
-Galactose -phosphate pyranose form)	$C_6H_{13}O_9P$ 260 14		27 70	5 04	11 91	$[\alpha]_D^{18}$ + 148 5°	Intermediate of galactose metabolism	22
Galactosamine -phosphate	$C_6H_{14}NO_8P$ 259 15		27 81	5 45	11 95	–	Formed from galactosamine in brain tissue extracts and *Saccharomyces fragilis*	23
-Glucose 1-phosphate (pyranose form) ('CORI ester')	$C_6H_{13}O_9P$ 260 14		27 70	5 04	11.91	$[\alpha]_D^{18}$ + 120°	Intermediate of glucose-glycogen interconversion	24
Glucose 6-phosphate (pyranose form) ('ROBISON ester')	$C_6H_{13}O_9P$ 260 14		27 70	5 04	11 91	$[\alpha]_D^{18}$ + 34 2°	Intermediate of glycolysis	25
D-Glucose 1,6-diphosphate (pyranose form)	$C_6H_{14}O_{12}P_2$ 340 12		21 19	4 15	18 21	$[\alpha]_D^{18}$ – 19° (pH 8)	Intermediate of glucose-glycogen interconversion	26

Table 2 (continued) Sugar phosphates of importance to mammals

Name	Formula and mol. wt.	Structure	Elementary composition			Specific rotation	Biological function	F
			C	H	P			
D-Glucosamine 6-phosphate	$C_6H_{14}NO_8P$ 259.15		27.81	5.45	11.95	$[\alpha]_D^{25}$ + 56°	Formed from D-glucosamine by yeast enzyme preparations and by hexokinase	
D-Gluconic acid 6-phosphate	$C_6H_{13}O_{10}P$ 276.14		26.10	4.75	11.22	$[\alpha]_{5461}^{20}$ + 0.2°	Intermediate of pentose phosphate cycle	
N-Acetylglucosamine 1-phosphate	$C_8H_{16}NO_9P$ 301.19		31.90	5.35	10.28	$[\alpha]_D^{25}$ + 79°	Intermediate in the formation of UDP *N*-acetylglucosamine and *N*-acetylneuraminic acid	2
N-Acetylglucosamine 6-phosphate	$C_8H_{16}NO_9P$ 301.19		31.90	5.35	10.28	$[\alpha]_D^{25}$ + 29.5°	Intermediate in the formation of *N*-acetylglucosamine and *N*-acetylneuraminic acid	31
D-Mannose 6-phosphate (pyranose form)	$C_6H_{13}O_9P$ 260.14		27.70	5.04	11.91	$[\alpha]_{5461}^{20}$ + 15.1°	Intermediate of mannose metabolism	31
N-Acetylmannosamine 6-phosphate	$C_8H_{16}NO_9P$ 301.19		31.90	5.35	10.28	$[\alpha]_D^{23}$ + 11.2°	Intermediate in biosynthesis of *N*-acetylneuraminic acid	32
N-Acetylneuraminic acid 9-phosphate	$C_{11}H_{20}NO_{12}P$ 389.26		33.94	5.18	7.96	–	Intermediate in formation of *N*-acetylneuraminic acid from *N*-acetylmannosamine	33

2 (concluded) Sugar phosphates of importance to mammals

Name	Formula and mol wt	Structure	Elementary composition C	H	P	Specific rotation	Biological function	Refe ence
edoheptulose -phosphate	$C_7H_{15}O_{10}P$ 290 17		28 98	5 21	10 67	–	Intermediate of pentose phosphate cycle	34
edoheptulose 1,7-diphosphate	$C_7H_{16}O_{13}P_2$ 370 15		22 71	4 36	16 74	–	Intermediate of pentose phosphate cycle	35
ctose 1-phosphate	$C_{12}H_{23}O_{14}P$ 422 28	 (probable structure)	34 13	5 49	7 33	$[\alpha]_D^{25}$ + 99 5°	Possible intermediate in lactose synthesis. Formed from UDP galactose and glucose 1-phosphate	36

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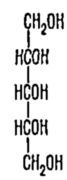
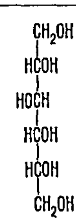
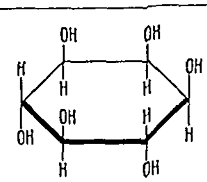
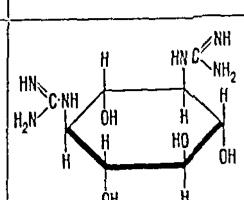
[1] Ballou, C E, in Lardy et al (Eds), *Biochemical Preparations*, vol 7, Wiley, New York, 1960, page 45
[2] Meyerhof, O, *Bull Soc Chim biol (Paris)*, 20, 1033 and 1345 (1938) Ballou and Fischer, *J Amer chem Soc*, 77, 3329 (1955)
[3] Baer and Fischer, *J biol Chem*, 128, 491 (1939), Baer and Fischer, in Ball et al (Eds), *Biochemical Preparations*, vol 2, Wiley, New York, 1952, page 31
[4] Kiessling, W, *Ber dtsch chem Ges*, 68, 243 (1935), Ballou, C E, in Shemin et al (Eds), *Biochemical Preparations*, vol 5, Wiley, New York, 1957, page 66
[5] Neuberg and Lustig, *Arch Biochem*, 1, 311 (1942), Ballou and Fischer, *Abstr chem Soc 126th Meeting* 1954, page 7D
[6] Negelein and Brömel, *Biochem Z*, 301, 135 (1939)
[7] Baer, E, *J biol Chem*, 185, 763 (1950)

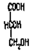
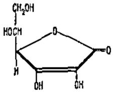
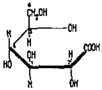
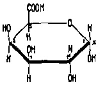
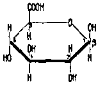
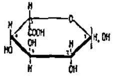
[20] Neuberg et al, *Arch Biochem*, 3, 33 (1944), Tanko, B, *Abstracts of the Communications of the 1st International Congress of Biochemistry*, Cambridge, 1949, page 222
[21] Sable, H Z, in Ball et al (Eds), *Biochemical Preparations*, vol 2, Wiley, New York, 1952, page 52
[22] Kosterlitz, H W, *Biochem J*, 37, 318 (1943), Hansen et al, in Westerfeld et al (Eds), *Biochemical Preparations*, vol 4, Wiley, New York, 1955, page 1

Table 3 Polyhydric alcohols of importance to mammals

Name	Formula and mol. wt.	Structure	Specific rotation	Occurrence
Glycerol	$C_3H_8O_3$ 92.10		–	Wide occurrence in lipids of mamm tissues. Sweet taste. Component of walls of many GRAM-positive bacteri
Erythritol	$C_4H_{10}O_4$ 122.12		Inactive	Isolated from human urine [3]
Ribitol (adonitol)	$C_5H_{12}O_5$ 152.15		–	Component of riboflavin (vitamin B_2, page 472). Also found in *Adonis vern.* Component of cell walls of many GR positive bacteria [1]
L-Arabitol	$C_5H_{12}O_5$ 152.15		$[\alpha]_D$ − 7.2	Isolated from human urine in pentosur
Sorbitol (D-glucitol)	$C_6H_{14}O_6$ 182.17		$[\alpha]_D$ − 1.8	Constituent of seminal plasma in many sp cies including man
Myoinositol [2] ('mesoinositol')	$C_6H_{12}O_6$ 180.16		Inactive	Widely distributed in plant and anim kingdoms. Found both free and combine in muscle, heart, liver and other tissue Component of brain cephalin. The hexaphosphate (phytin) is the organi phosphorus reserve material of green plant (See also page 491)
Streptidine	$C_8H_{18}N_6O_4$ 262.27		–	Component of streptomycin

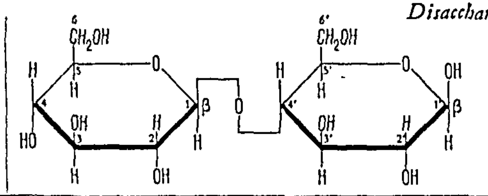
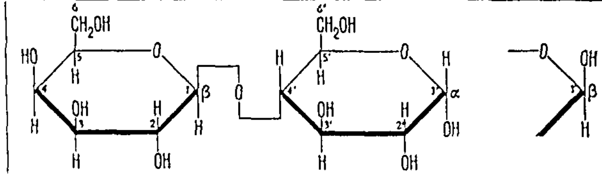
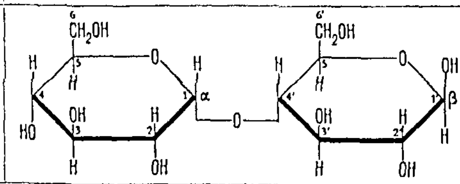
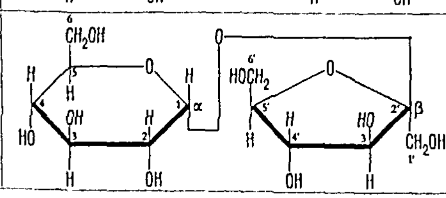
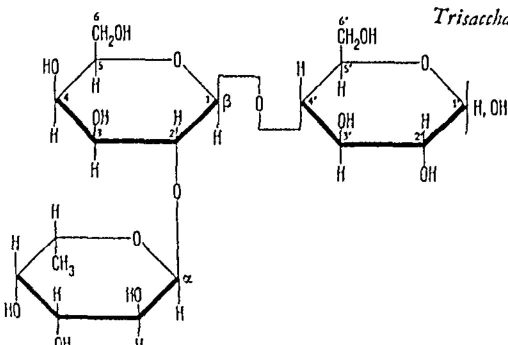
References
[1] ROGERS, H.J., *Biochem. Soc. Symp.*, No. 22, 55 (1963).
[2] ANGYAL and ANDERSON, *Advanc. Carbohyd. Chem.*, 14, 135 (1959).
[3] TOUSTER et al., *J. biol. Chem.*, 235, 951 (1960).
[4] TOUSTER and HARWELL, *J. biol. Chem.*, 230, 103 (1958).

ble 4 Oxidation products of carbohydrates

Name	Formula and mol wt	Structure	Specific rotation	Occurrence
		Aldonic acids		
D-Glyceric acid (D-α,β-dihydroxy-propionic acid)	$C_3H_6O_4$ 106 08		–	As phosphate esters (see Table 2, page 317) which are intermediates in glycolysis
L-Ascorbic acid (L-xyloascorbic acid, vitamin C)	$C_6H_8O_6$ 176 13		$[\alpha]_D^{20}$ + 49°	See under 'Vitamins', page 489
D-Gluconic acid (dextronic acid)	$C_6H_{12}O_7$ 196 16		$[\alpha]_D^{20}$ – 6 7° → + 17.5°	As phosphate ester (see Table 2, page 320), intermediate in pentose phosphate cycle
		Uronic acids		
α D-Galacturonic acid	$C_6H_{10}O_7$ 194 14		$[\alpha]_D^{20}$ + 100° → + 68°	Main component of pectins Also occurs in some plant gums and mucilages and bacterial polysaccharides (see Table 6, pages 325 and 328)
β-D-Glucuronic acid	$C_6H_{10}O_7$ 194 14		$[\alpha]_D^{20}$ + 12° → + 36°	Component of mucopolysaccharides (see Table 6, pages 325, 327 and 328) Many aliphatic and aromatic hydroxy compounds and acids are excreted as glucuronides[†] (see also page 442) Has pyranose form in natural products
L-Iduronic acid	$C_6H_{10}O_7$ 194 14		–	Component of chondroitin sulphate B (see Table 6, page 326)

References [†] TEAGUE, R. S., *Advanc Carbohyd Chem*, 9 185 (1954), WILLIAMS, R. T, *Detoxication Mechanisms*, 2nd ed, Chapman & Hall, London, 1959.

Table 5 Oligosaccharides of importance to mammals [1]

Name	Formula and mol. wt.	Structure	Specific rotation	Remarks
		Disaccharides		
Cellobiose (4′-[β-D-glucopyranosido]-β-D-glucopyranose)	$C_{12}H_{22}O_{11}$ 342.30		$[\alpha]_D^{20}$ + 14.2° → + 34.6°	Breakdown product of cellulose arising in herbivores in the course of digestion. Component also of lichenin
Lactose (4′-[β-D-galactopyranosido]-D-glucopyranose)	$C_{12}H_{22}O_{11}$ 342.30		α-form, 1 H_2O: $[\alpha]_D^{20}$ + 85° → + 52.6° β-form: $[\alpha]_D^{20}$ + 34.9° → + 55.4°	Constituent of mammalian milk (4–8%). Only faintly sweet
Maltose (4′-[α-D-glucopyranosido]-β-D-glucopyranose)	$C_{12}H_{22}O_{11}$ 342.30		β-form, 1 H_2O: $[\alpha]_D^{20}$ + 111.7° → + 130.4°	Breakdown product of starch and glycogen arising in the course of digestion. Found free in some plants (barley) and in honey
Sucrose (saccharose, cane sugar, beet sugar, α-D-glucopyranosido-β-D-fructofuranoside)	$C_{12}H_{22}O_{11}$ 342.30		$[\alpha]_D^{20}$ + 66.53°	Almost universal occurrence in the vegetable kingdom
		Trisaccharide		
Fucosidolactose (2-[α-L-fucopyranosido]lactose)	$C_{18}H_{32}O_{15}$ 488.44		–	Occurs in traces in human milk along with other di-, tri-, penta- and hexasaccharides [2]

References [1] For a detailed and [illegible]

Table 6 Polysaccharides of [illegible]

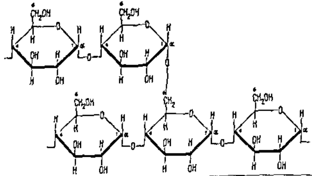
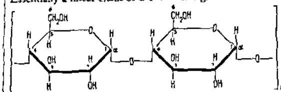
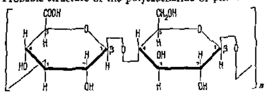
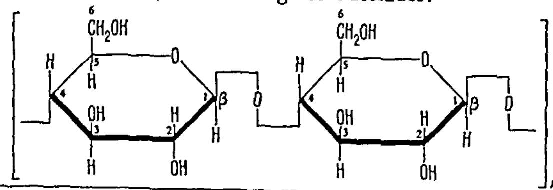
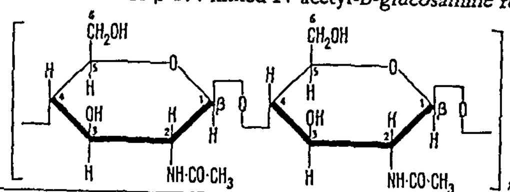
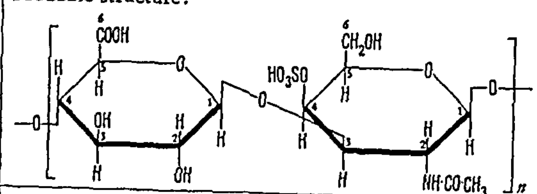
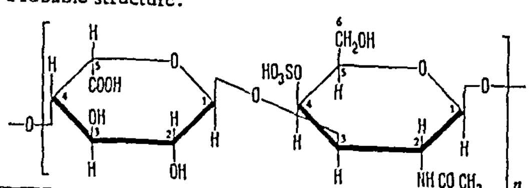
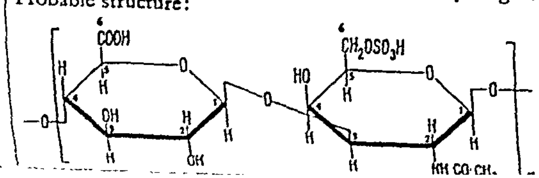
Name	Mol. wt.	Structure	Specific rotation	Remarks	References
Amylopectin (α-amylose, B fraction of starch)	Up to 52 × 10⁶ for potato amylopectin	Highly-branched molecule composed of several hundred unit-chains, each of which comprises 20-26 α-1 4-linked glucose residues, the unit-chains are interlinked by glycosidic bonds from the reducing group to C-6 of a glucose residue in an adjacent chain 	$[\alpha]_D^{20}$ + 150°	Main constituent of starch (usually ca. 80%)	1–3
Amylose (β-amylose, A-fraction of starch)	$(323)_n$, up to 1 × 10⁶	Essentially a linear chain of α-1 4 linked glucose residues 	$[\alpha]_D^{20}$ + 220°	Constituent of starch (ca 20%). Absent in some starches, e g, that of 'waxy' maize (corn)	1–3
Bacterial capsule polysaccharides	–	Polymers with a composition depending on the type of organism Thus the polysaccharide of pneumococcus type II is composed of glucose, glucuronic acid and rhamnose, that of pneumococcus type III of glucose and glucuronic acid, that of pneumococcus type XIV of glucose, galactose and *N*-acetylglucosamine, that of streptococci groups A and C of glucuronic acid and *N*-acetylglucosamine, that of *Haemophilus influenzae* of ribose phosphate. Probable structure of the polysaccharide of pneumococcus type III: 	–	Specific oligosaccharide units of the capsular polysaccharides are responsible for the specific antigenic properties of each bacterial type	9, 10, 12
Bacterial cell-wall polysaccharides (mureins)	–	Very large macromolecules of complex structure The amino sugars *N*-acetylglucosamine and *N*-acetylmuramic acid form strands of linear unbranched muropolysaccharides making up the backbone of the murein These strands are attached by amide bonds to the carboxylic groups of the muramic acids and carry short oligopeptide side chains Additional peptide bonds occur between different side chains of neighbouring muropolysaccharide strands, so that a close two- or three-dimensional mesh is formed	–	Found particularly in Gram-positive bacteria, in smaller amount also in some Gram-negative bacteria	10 11

Table 6 (continued) Polysaccharides of importance to mammals *(for references see page 328)*

Name	Mol. wt.	Structure	Specific rotation	Remarks	References
Cellulose	$(323)_n$, up to 1.7×10^6	Linear chain of β-1:4-linked glucose residues: 	–	Chief structural polysaccharide of plants. Also found in algae, bacterial membranes, and as tunicin in some lower animals. *Not digested by man*	3
Chitin	$(203.19)_n$, ca. 4×10^5	Linear chain of β-1:4-linked *N*-acetyl-D-glucosamine residues: 	$[\alpha]_D^{20}$ − 14.7° (in HCl)	Skeletal substance of molluscs and insects. Also found in lower plants and fungi	4
Chondroitin sulphate A (chondroitin 4-sulphate)	Polydisperse	Polymer composed of D-glucuronic acid, *N*-acetyl-D-galactosamine and sulphate residues. Probable structure: 	$[\alpha]_D$ − 28° to − 32°	Present in mammalian cartilaginous tissue	5, 6
Chondroitin sulphate B (β-heparin, dermatan sulphate)	Polydisperse	Polymer composed of L-iduronic acid, *N*-acetyl-D-galactosamine and sulphate residues. Probable structure: 	$[\alpha]_D$ − 60° to − 32°	Present in mammalian cartilaginous tissue	5, 6
Chondroitin sulphate C (chondroitin 6-sulphate)	Polydisperse	Polymer composed of D-glucuronic acid, *N*-acetyl-D-galactosamine and sulphate residues. Probable structure: 	$[\alpha]_D$ − 16° to − 22°	Present in mammalian cartilaginous tissue	5, 6

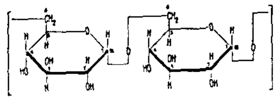
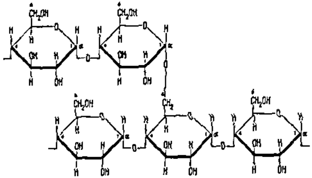
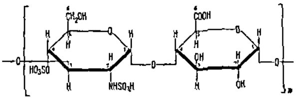
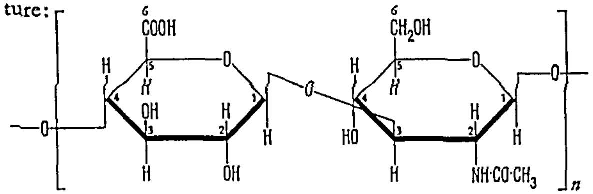
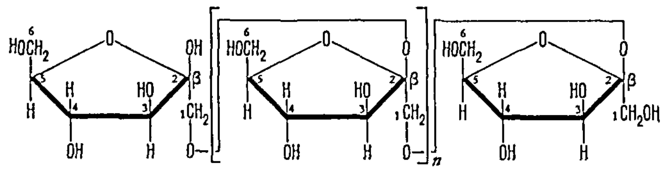
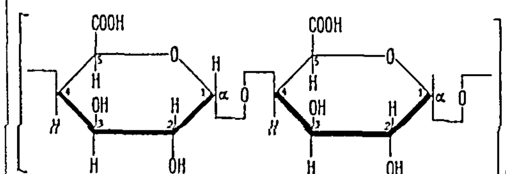
Dextrans	$(323)_n$, ca. 4×10^6	Probably α-1 6-linked glucose residues in branched or straight chains, for instance 	–	Produced extracellularly by bacteria, e.g., *Leuconostoc mesenteroides*. Partially degraded dextrans are used as blood-plasma substitutes	
Glycogen (liver starch)	Polydisperse, for most glycogens at least 2×10^6	Highly-branched molecule resembling amylopectin and consisting of unit chains of α-1 4-linked glucose residues interlinked by α-1·6-glycosidic bonds 	$[\alpha]_D^{25}$ ca. + 200° (water)	Reserve carbohydrate of animal tissues. Converted in muscle to lactic acid during glycolysis (see page 389). Also present in yeast. Has been synthesized by action of heart or liver phosphorylase on glucose 1-phosphate	2, 3, 8
Glycoproteins	–	Proteins containing covalently bound carbohydrate residues other than uronic acids. The carbohydrates are D-galactose, D-mannose, D-glucosamine, D-galactosamine, L-fucose and sialic acid; some plant glycoproteins contain also arabinose and xylose. The carbohydrate content ranges from 2-3% in γG-globulin up to 75% in the blood-group substances. In many glycoproteins aspartic acid serves as the linking residue between the protein and carbohydrate moieties. In orosomucoid, transferrin, fibrinogen and ovalbumin there seems to be a common structure consisting of (a) a core of D-mannose and D-glucosamine, the latter linked to aspartic acid, and (b) an outer envelope containing D-galactose, L-fucose and in some cases sialic acid	–	Widely distributed in nature. The majority of plasma proteins, many milk and egg proteins, mucins, connective tissue components, hormones and a number of enzymes (bovine pancreatic ribonuclease, horse serum cholinesterase, human serum alkaline phosphatases) have been characterized as glycoproteins	12
Heparin	ca. 17 000	Polymer composed of D-glucosamine, D-glucuronic acid and sulphate residues. Probable structure: 	–	Occurs in animal tissues. Blood anticoagulant	5, 6

Table 6 (concluded) Polysaccharides of importance to mammals

Name	Mol. wt.	Structure	Specific rotation	Remarks	Reference
Hyaluronic acid	ca. 1×10^6	Polymer composed of *N*-acetyl-D-galactosamine and D-glucuronic acid residues. Probable structure: 	–	Widely distributed in tissues and intercellular fluids	5, 6
Inulin	$(162.14)_n$, ca. 5000	Linear chain of about 30 β-1:2-linked fructofuranose units: 	$[\alpha]_D^{20}$ – 40°	Reserve carbohydrate of many plants, alone or with starch	3
Keratan sulphate (keratosulphate)	Polydisperse	Polymer composed of D-galactose, *N*-acetyl-D-glucosamine and sulphate residues. It is probably (1→3)-*O*-β-D-galactopyranosyl-(1→4)-2-acetamido-2-deoxy-6-*O*-sulpho-β-D-glucopyranose	–	Originally isolated from the bovine cornea. Occurs in animal connective tissues, e.g., nucleus pulposus, costal cartilage	6
Pectic acid (pectins)	$(346)_n$, up to 5×10^4	Probably a linear chain of α-1:4-linked D-galacturonic acid residues: 	$[\alpha]_D^{20}$ ca. + 240°	Important cell-wall constituent of plants. Occurs as Ca salt or methyl ester	8
Teichoic acids	–	Linear polymers of either glycerol or ribitol phosphate subunits connected in 1,3- or 1,5-phosphodiester linkages respectively. The hydroxyl groups of the polyol monomers may be substituted with D-alanine in an ester bond and with different glycosidically linked mono- or oligosaccharides functioning as the determinant groups of the teichoic acid antigens	–	In cell walls of some bacteria (e.g., *Staphylococcus aureus*), where the teichoic acid is covalently bound to the muropolysaccharide strands of murein	11

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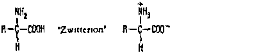
nino acids [1]

An amino acid is any compound containing one or more amino)ups and one or more carboxylic acid groups Those of biologi- importance generally contain an amino group in the α-position a carboxyl group, i e , they are of the general structure



The asymmetry about the α-carbon atom renders the amino ds optically active, except when R = H, as in glycine. Their menclature is similar to that adopted for the carbohydrate series d involves the use of the small capital letters D and L to indicate

proteins is referred to simply as the L-isomer. This is not, of

The majority of amino acids are stable compounds and melt ove 200 °C with decomposition, they are insoluble in the com- on neutral solvents except water, and can usually be recrystallized om aqueous ethanol Their salt-like behaviour can be ascribed to eir existence as internal salts, or 'zwitterions' (see above)

The amino acids behave as amphoteric compounds and possess iaracteristic isoelectric points, many of their physical properties hibit maxima and minima at these points

Amino acid analysis may be carried out by adsorption chromato- 'aphy on starch, partition chromatography on silica gel and iper, ion-exchange chromatography, electrophoresis, thin-film iromatography, and vapour phase chromatography[3,4] A single n-exchange column is now sufficient for the separation of all the ımmon amino acids and an automatic analyser based on this :ocedure is now commercially available Many methods exist for ie quantitative estimation of amino acids isotope dilution, enzy- atic assay, microbial assay and chemical methods[1,4]

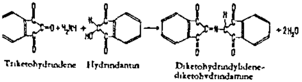
There are three methods of quantitative estimation applicable to ie majority of amino acids

1) Amino acids containing a primary amino group react with nitrous acid to give nitrogen

$$R-CH(NH_2)COOH + HNO_2 \longrightarrow R-CH(OH)\cdot COOH + N_2 + H_2O$$

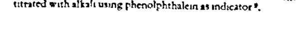
This forms the basis of VAN SLYKE's method of estimation, the nitrogen being measured volumetrically[5] or manometrically[6]

2) Amino acids containing free carboxylic and primary α-amino groups are oxidized on heating with ninhydrin



Ninhydrin (triketohydrindene hydrate) Hydrindantin Aldehyde

Either NH_3 or CO_2 can be quantitatively measured[7] Alternatively, the blue colour forming above pH 2 when the reaction mixture is heated, due to the following reaction, can be used for quantitative estimations[8]



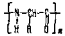
Triketohydrindene Hydrindantin Diketohydrindylidene-diketohydrindamine

c) Formaldehyde reacts with the amino groups of an amino acid and thus reduces their basicity, this allows the acid to be directly titrated with alkali using phenolphthalein as indicator[9].

constituents of physiologically active compounds.

Polypeptides

Polypeptides are compounds built up of the re;



They are derived from amino acids by elimination (gives rise to the peptide bond –HN · CO– between

solve readily in aqueous salt solutions, *prolamines*, uble in alcohol–water mixtures but not in pure al water, and various other classes

levels of structure is preferable[11].

spectrophotometric methods[14]

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[4]

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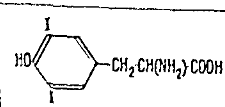
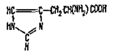
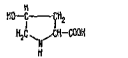
[6] VAN SLYKE, D D , *J biol Chem* , 83, 425 (1929)
[7] VAN SLYKE et al , *J biol Chem* , 141 627 671 (1941) ...
[8]
[9]

[14] TIMASHEFF and GORBUNOFF, *Ann Rev Biochem* , 36, 13 (1

Table 7 Physical and chemical properties of amino acids occurring as protein constituents *(for references see page 333)*

Name	Symbol*	Formula and mol. wt.	Structure	Elementary composition (%) C	H	N	Solubility (grammes per 100 g water at 25 °C)	Specific rotation: Temperature (°C)	Concentration**	Solvent	$[\alpha]_D$	Special properties *Organism for microbiological assay*	Special occurrence and biological function
α-Alanine (α-amino-propionic acid)	Ala	$C_3H_7NO_2$ 89.09	$CH_3{\cdot}CH(NH_2){\cdot}COOH$	40.44	7.92	15.72	16.72	25 25 20	2.06 10.00 1.78	6-N HCl Water 3-N NaOH	+ 13.70 + 2.41 + 3.0	*Leuconostoc (Lactobacillus) citrovorum* 8081	–
Arginine (α-amino-δ-guanido-*n*-valeric acid)	Arg	$C_6H_{14}N_4O_2$ 174.20	$HN{=}C(H_2N){\cdot}NH{\cdot}[CH_2]_3{\cdot}CH(NH_2){\cdot}COOH$	41.37	8.10	32.16	15	23.3 20 20	1.65 3.48 0.87	6-N HCl Water 0.5-N NaOH	+ 27.58 + 12.5 + 11.8	Basic. Gives SAKAGUCHI colour reaction with α-naphthol and sodium hypohalite *Streptococcus faecalis* 9790; *Leuconostoc citrovorum*	Intermediate in ornithine cycle of urea synthesis (see pages 442–444) and in creatine synthesis (see pages 437–438)
Asparagine (aspartic acid β-monoamide; α-amino-β-carbamyl-propionic acid)	Asn or Asp(NH₂) Asp | NH_2	$C_4H_8N_2O_3$ 132.12	$NH_2{\cdot}CO{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$	36.36	6.10	21.20	2.46	20 20 20	2.24 1.41 11.23	3.4-N HCl Water 2.5-N NaOH	+ 34.26 – 5.30 – 6.35	Hydrolysed by hot acid or specific enzymes to give NH_3 + aspartic acid	Found in free state in many plant tissues, especially etiolated seedlings
Aspartic acid (aminosuccinic acid)	Asp	$C_4H_7NO_4$ 133.10	$HOOC{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$	36.10	5.30	10.52	0.50	24 18 18	2.02 1.33 1.33	6-N HCl Water 3-N NaOH	+ 24.6 + 4.7 – 1.7	Acidic. Yields 2 moles of CO_2 and 1 mole of NH_3 in ninhydrin reaction *Leuconostoc mesenteroides* P-60, 8042	Involved in transformation of citrulline to arginine (see pages 442–444), and in biosynthesis of purines and pyrimidines (see pages 433 and 438–439)
Cysteine (α-amino-β-thiolpropionic acid)	Cys	$C_3H_7NO_2S$ 121.16	$HS{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$	29.74 Sulphur 26.46	5.82	11.56	Very soluble	26	12.1	1-N HCl	+ 7.6	Readily autoxidized in neutral or basic solution to cystine	Interconvertible with cystine by oxido-reduction. Component of glutathione (see page 438). Some aromatic compounds are excreted in urine as derivatives of *N*-acetylcysteine (mercapturic acids) (see page 445)
Cystine (di-[α-amino-propionic]-β-disulphide)	Cys | Cys	$C_6H_{12}N_2O_4S_2$ 240.30	$S{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$ | $S{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$	29.99 Sulphur 26.69	5.03	11.66	0.011	24 18.5	1.0 0.4	1-N HCl 0.2-N NaOH	–214.4 – 70.0	Readily reduced to cysteine *Leuconostoc mesenteroides* P-60, 8042; *Lactobacillus arabinosus*	Occurs abundantly in hair, keratin and insulin. The disulphide bond links together different polypeptide chains or different parts of the same polypeptide chain within the protein molecule
3,5-Di-iodo-tyrosine***	–	$C_9H_9NO_3I_2$ 432.99		24.97 Iodine 58.62	2.10	3.23	0.062	20 20	5.08 4.41	1.1-N HCl 3.4-N NH_4OH	+ 2.89 + 2.27	–	Occurrence confined to protein of thyroid gland (thyroid hormones; see page 440)

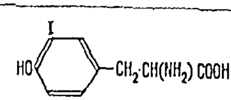
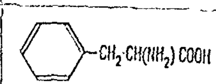
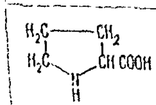
Glutamic acid (α aminoglutaric acid)	Glu	$C_5H_9NO_4$ 147 13	$HOOC(CH_2)_2CH(NH_2)COOH$	40 82	6 17	9 52	0 843	22.4 18 18	1 00 1 47 1 47	6-N HCl Water 1-N NaOH	+ 31.2 + 11 5 + 10 96	Acidic. On boiling in solution over a wide pH range (4–10) cyclizes to pyrrolidonecarboxylic acid *Leuconostoc mesenteroides* P-60, 8042, *Lactobacillus arabinosus*	Component of glutathione (see page 438) and of the folic acid vitamins (see page 479). Present in high concentration in tissues. More readily dehydrogenated in animal tissue than any other amino acid, and also more reactive in enzymic transamination reactions
Glutamine (glutamic acid β-monoamide, α-amino-γ-carbamyl-butyric acid)	Gln or Glu(NH$_2$) or Glu | NH$_2$	$C_5H_{10}N_2O_3$ 146.15	$NH_2CO(CH_2)_2CH(NH_2)COOH$	41 09	6 90	19 17	3 6 (at 18°C)	22	3.6	Water	+ 5 0	On heating in solution to ca 100°C at near neutrality cyclizes to ammonium salt of pyrrolidonecarboxylic acid. Amide group reacts with nitrous acid in presence of acetic acid to release N_2. Hydrolysed by specific enzyme to ammonium glutamate	Occurs in the free state in animal tissues and many plants, e g , sugar beet. Phenylacetic acid is excreted by man as phenacetylglutamine (see page 445). Intermediate carrier of amino groups See also page 434
Glycine (aminoacetic acid)	Gly	$C_2H_5NO_2$ 75 07	NH_2CH_2COOH	32 00	6 71	18 66	24 99	–	–	–	–	Optically inactive. Gives green colour with o-phthalaldehyde *Leuconostoc mesenteroides* P-60, 8042	In many animals benzoic acid is excreted as benzoylglycine (hippuric acid) (see pages 444 and 445) Component of glutathione (see page 438). Metabolite in synthesis of creatine, porphyrins, purines (see page 434). Formed from serine in mammals (see page 432)
Histidine (α-amino-β [4 imidazole]-propionic acid)	His	$C_6H_9N_3O_2$ 155 16		46 45	5 85	27 08	4 29	25 25 20	1 00–4 05 0 75–3 77 0 77	6 1-N HCl Water 0 5-N NaOH	+ 13 34 – 38 95 – 10 9	Basic. Gives biuret test, couples with diazotized sulphanilic acid to give intense red colour (PAULY reaction) *Leuconostoc mesenteroides* P-60, 8042	Decarboxylated to histamine. Constituent of the carnosine (β-alanylhistidine) found in muscle
δ Hydroxylysine (α,ε-diamino-δ hydroxy-n-caproic acid)	Hyl	$C_6H_{14}N_2O_3$ 162.19	$NH_2CH_2CH(OH)(CH_2)_2CH(NH_2)COOH$	44 43	8 70	17 27	–	25	2.0	6-N HCl	+ 14 5	Reacts with periodate to yield formaldehyde and ammonia	Has been found as protein constituent only in collagen and gelatin. Phosphate ester occurs naturally[3]
Hydroxyproline (γ hydroxy-pyrrolidine-α-carboxylic acid)	Hyp	$C_5H_9NO_3$ 131 13		45 80	6 92	10 68	36 11	20 22.5 20	1 31 1 00 0 65	1-N HCl Water 0 5-N NaOH	– 47 3 – 75 2 – 70 6	Has no primary α-amino group and therefore differs in many respects from primary amino acids, e g , with nitrous acid does not release nitrogen. Oxidized by hypochlorite to give hydroxypyrroline Decarboxylated by ninhydrin to give reddish colour below pH 4 4, yellowish colour at higher pH. Forms bright blue condensation product with isatin	Component of gelatin, collagen and urinary di- and tripeptides[2] See also page 432

* Recommended by the Combined Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International

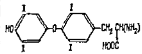
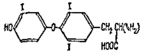
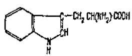
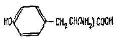
** As grammes per 100 ml solution unless otherwise stated

*** For chromatographic separation from other iodinated amino acids and estimation see BLOCK and WEISS[1].

Table 7 (continued) Physical and chemical properties of amino acids occurring as protein constituents

Name	Symbol*	Formula and mol. wt.	Structure	Elementary composition (%) C	H	N	Solubility (grammes per 100 g water at 25 °C)	Specific rotation: Temperature (°C)	Concentration**	Solvent	$[\alpha]_D$	Special properties *Organism for microbiological assay*	Special occurrence and biological function
Leucine (α-amino-*iso*caproic acid)	Leu	$C_6H_{13}NO_2$ 131.18	$(CH_3)_2CH{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$	54.94	9.99	10.68	2.19	25 25 20	2.00 2.00 1.31	6-N HCl Water 3-N NaOH	+ 15.20 − 10.57 + 7.6	*Lactobacillus arabinosus* 17-5, 8014; *Lactobacillus helveticus*; *Streptococcus faecalis*; *Leuconostoc mesenteroides* P-60, 8042	–
Isoleucine (α-amino-β-methyl-*n*-valeric acid)	Ile	$C_6H_{13}NO_2$ 131.18	$CH_3{\cdot}CH_2{\cdot}CH(CH_3)\,CH(NH_2)\,COOH$	54.94	9.99	10.68	2.93 (at 20 °C)	20 20 20	5.09 3.10 3.34	6.1-N HCl Water 0.33-N NaOH	+ 40.61 + 11.29 + 11.09	*Lactobacillus arabinosus* 17-5, 8014; *Lactobacillus helveticus*; *Streptococcus faecalis*; *Leuconostoc mesenteroides* P-60, 8042	–
Lysine (α,ε-diamino-*n*-caproic acid)	Lys	$C_6H_{14}N_2O_2$ 146.19	$NH_2\,(CH_2)_4\,CH(NH_2)\,COOH$	49.30	9.65	19.16	Very soluble	23 20	2.00 6.50	6-N HCl Water	+ 25.9 + 14.6	Basic. Can be precipitated with phosphotungstic acid. Dry heating of proteins containing lysine causes an apparent loss of lysine *Streptococcus faecalis* 9790; *Leuconostoc mesenteroides* P-60, 8042	–
Methionine (α-amino-γ-methylthiol-*n*-butyric acid)	Met	$C_5H_{11}NO_2S$ 149.21	$CH_3{\cdot}S\,CH_2{\cdot}CH_2{\cdot}CH(NH_2)\,COOH$	40.25	7.43	9.39	3.35 (for DL-acid)	20 25	5.00 0.80	3-N HCl Water	+ 23.40 − 8.11	*Leuconostoc mesenteroides* P-60, 8042; *Lactobacillus fermenti* 36 (for DL-acid)	Provides the sulphur atom for cysteine biosynthesis (see 'Cystathionine', Table 8, page 335). Carrier of 'active' methyl groups
				Sulphur 21.49									
3-Monoiodo-tyrosine	–	$C_9H_{10}NO_3I$ 307.09		35.20	3.28	4.56	–	20	5.00	1-N HCl	− 4.4	–	Occurrence confined to protein of thyroid gland (thyroid hormones; see page 440)
				Iodine 41.32									
Norleucine (α-aminocaproic acid)	–	$C_6H_{13}NO_2$ 131.18	$CH_3\,(CH_2)_3\,CH(NH_2)\,COOH$	54.94	9.99	10.68	1.15 (at 18 °C)	20	4.3	6-N HCl	+ 21.3	–	Has not been proved to be a protein constituent[4]
Phenylalanine (α-amino-β-phenyl-propionic acid)	Phe	$C_9H_{11}NO_2$ 165.19		65.44	6.71	8.48	2.965	20	1.93	Water	− 35.14	*Leuconostoc mesenteroides* P-60, 8042	Can be converted to tyrosine in the human body (see page 398)
Proline (pyrrolidine-α-carboxylic acid)	Pro	$C_5H_9NO_2$ 115.13		52.16	7.88	12.17	162.3	20 23.4 20	0.57 1.00 2.42	0.5-N HCl Water 0.6-N KOH	− 52.6 − 85.0 − 93.0	Neutral. Soluble in alcohol. Chemically very similar to hydroxyproline *Leuconostoc mesenteroides* P-60, 8042; *Lactobacillus brevis*	Protein constituent. See also page 432

Constituents of Living Matter – Amino Acids

Serine (α-amino-β hydroxy propionic acid)	Ser	$C_3H_7NO_3$ 105 09	$HO\,CH_2{\cdot}CH(NH_2)\,COOH$	34 29	6 71	13 33	5 023 (for DL-acid)	25 20	9 34 10 41	1-N HCl Water	+ 14 95 − 6 83	Split by periodate or lead tetraacetate to formaldehyde and glyoxylic acid. Gives biuret test. Acid hydrolysis of protein leads to partial destruction *Leuconostoc mesenteroides* P-60, 8042, *Lactobacillus delbrueckii* LD 5, *Lactobacillus helveticus*	Most of the serine in phosphoproteins (vitellin, casein) occurs in form of phosphoserine[4]. Phosphatidylserine is a component of some phospholipids
Threonine (β methylserine, α amino-β hydroxy-butyric acid)	Thr	$C_4H_9NO_3$ 119 12	$CH_3\,CH(OH)\,CH(NH_2)\,COOH$	40 33	7 62	11 76	-	26	1 63 (g solute per 100 g solution)	Water	− 9 1	Some properties similar to those of serine. Oxidized by periodate to acetaldehyde and glyoxylic acid *Streptococcus faecalis* 9790, *Leuconostoc mesenteroides* P 60, 8042	Phosphothreonine has been found in casein hydrolysates[6]
Thyroxine (3,5,3′,5′-tetraiodo thyronine)	-	$C_{15}H_{11}NO_4I_4$ 776 88		23 19	1 43	1 80 Iodine 65 34	0 001	-	3 (g solute per 100 g solution)	0 13-N NaOH in 70% ethanol	− 4 4	-	Occurrence confined to protein of thyroid gland (thyroid hormones; see page 440)
3,5,3′-Tri iodo-thyronine	-	$C_{15}H_{12}NO_4I_3$ 650 98		27 68	1 86	2.15 Iodine 58 48	-	29 5	4 75 (as hydrochloride)	1-N HCl-ethanol (1 2)	+ 21 5	-	Occurrence confined to protein of thyroid gland (thyroid hormones; see page 440)
Tryptophan (α amino-β [3-indolyl]-propionic acid)	Trp	$C_{11}H_{12}N_2O_2$ 204 23		64 69	5 92	13 72	1 14	20 22.7 20	1 02 1 00 2 42	0 5-N HCl Water 0 5-N NaOH	+ 2 4 − 31 5 + 6 17	Destroyed on prolonged heating in hot acid. Gives MILLON reaction (see Tyrosine, below) and FOLIN test. Gives colour reaction with *p*-dimethylaminobenzaldehyde and nitrous acid (EHRLICH test) *Lactobacillus arabinosus* 17–5, 8014, *Streptococcus faecalis*	-
Tyrosine (α-amino-β-[*p*-hydroxyphenyl]-propionic acid)	Tyr	$C_9H_{11}NO_3$ 181 19		59 66	6 12	7 73	0 045	20 18	4 40 0 90	6 3-N HCl 3 0 N NaOH	− 8 64 − 13 2	Reacts with Hg salts and nitrous acid to give red colour (MILLON reaction). Other less specific colour tests are reaction with α-nitroso-β-naphthol, reaction with FOLIN phenol reagent *Leuconostoc mesenteroides* P-60, 8042	Precursor of thyroxine, adrenaline and melanin (see page 440)
Valine (α-amino-isovaleric acid)	Val	$C_5H_{11}NO_2$ 117 15	$(CH_3)_2CH\,CH(NH_2)\,COOH$	51 26	9.46	11 96	8 85	20 20	3 4 3 58	6 N HCl Water	+ 28.8 + 6 42	*Lactobacillus arabinosus* 17–5, 8014, *Lactobacillus helveticus*, *Streptococcus faecalis*	-

* Recommended by the Combined Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry (*J biol Chem*, 241, 527 [1966]) and used in the descrip-

References

[1] ROCHE et al, in GLICK, D (Ed), *Methods of Biochemical Analysis*, vol 1, Wiley, New York, 1954, page 243, BLOCK and WEISS, *Amino Acid Hand-*

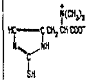
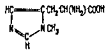
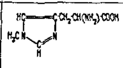
[2] MEILMAN et al, *J clin Invest*, 42, 40 (1963).

[3] ASTRUP et al, *Acta physiol scand*, 24, 202 (1952)

[4] CONSDEN et al, *Biochem J*, 39, 251 (1945)

Table 8 Physical and chemical properties of some amino acids not occurring in proteins but found in the free form

Name	Formula and mol. wt.	Structure	Elementary composition (%) C	H	N	Solubility (grammes per 100 g water at 25 °C)	Specific rotation: Temperature (°C)	Concentration (g per 100 ml solution)	Solvent	$[\alpha]_D$	Special properties	Occurrence and biological function
β-Alanine (β-amino-propionic acid)	$C_3H_7NO_2$ 89.09	$NH_2{\cdot}CH_2{\cdot}CH_2{\cdot}COOH$	40.44	7.92	15.72	Very soluble	–	–	–	–	–	Breakdown product of pyrimidines (see page 401). Occurs as constituent of pantothenic acid, coenzyme A, carnosine and anserine. See also page 434
α-Aminoadipic acid	$C_6H_{11}NO_4$ 161.16	$HOOC{\cdot}(CH_2)_3{\cdot}CH(NH_2){\cdot}COOH$	44.72	6.88	8.69	0.22 (at 20 °C)	–	–	–	–	Decomposes on heating to α-piperidone-α'-carboxylic acid	Intermediate in breakdown of lysine (see page 398)
α-Amino-*n*-butyric acid	$C_4H_9NO_2$ 103.12	$CH_3{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$	46.59	8.80	13.58	28 (for DL-acid)	20	5.46	Water	+ 7.86	–	Found in brain preparations[1]. Occurs as constituent of tripeptide ophthalmic acid in lens tissue[2]
γ-Amino-*n*-butyric acid	$C_4H_9NO_2$ 103.12	$NH_2{\cdot}(CH_2)_3{\cdot}COOH$	46.59	8.80	13.58	–	–	–	–	–	–	Found in brain[3], lung and heart[1] preparations
β-Amino*iso*butyric acid	$C_4H_9NO_2$ 103.12	$NH_2{\cdot}CH_2{\cdot}CH(CH_3){\cdot}COOH$	46.59	8.80	13.58	–	–	–	–	–	–	Breakdown product of thymine (see page 401)
δ-Aminolaevulinic acid (γ-keto-δ-amino-*n*-valeric acid)	$C_5H_9NO_3$ 131.13	$NH_2{\cdot}CH_2{\cdot}CO{\cdot}CH_2{\cdot}CH_2{\cdot}COOH$	45.80	6.92	10.68	–	–	–	–	–	Reduces BENEDICT's solution in the cold. Split by periodate to formaldehyde and succinic acid	Intermediate in porphyrin biosynthesis (see page 437)
Argininosuccinic acid	$C_{10}H_{18}N_4O_6$ 290.28	$HOOC{\cdot}CH(NH_2){\cdot}(CH_2)_3{\cdot}NH{\cdot}C({=}NH){\cdot}NH{\cdot}CH(COOH){\cdot}CH_2{\cdot}COOH$	41.38	6.25	19.30	–	24 24 24	2.9 2.9 2.9	Water 0.5-N NaOH 0.5-N HCl	+ 16.4 + 26.6 + 5.2	In aqueous solution cyclizes spontaneously with loss of water	Intermediary metabolite in ornithine cycle of urea synthesis[4] (see pages 442 and 444). Excreted in the urine of some mental defectives[5] (see page 449)
Carbamylaspartic acid (ureidosuccinic acid)	$C_5H_8N_2O_5$ 176.13	$HOOC{\cdot}CH_2{\cdot}CH(COOH){\cdot}NH{\cdot}CO{\cdot}NH_2$	34.10	4.58	15.90	0.4 (at 20 °C)	25	–	Water (Ba salt)	+ 24.1	–	Intermediate in biosynthesis of pyrimidines from aspartic acid in mammals and bacteria (see page 439)
Citrulline (α-amino-δ-ureido-*n*-valeric acid)	$C_6H_{13}N_3O_3$ 175.19	$NH_2{\cdot}CO{\cdot}NH{\cdot}(CH_2)_3{\cdot}CH(NH_2){\cdot}COOH$	41.14	7.48	23.99	–	21 21	5.00 5.00	0.3-N HCl Water	+ 17.9 + 3.5	Converted to ornithine by alkaline hydrolysis	Intermediate in ornithine cycle of urea synthesis (see pages 442–443)
Creatine (methyl-glycocyamine)	$C_4H_9N_3O_2$ 131.14	$HN{=}C(NH_2){\cdot}N(CH_3){\cdot}CH_2{\cdot}COOH$	36.64	6.92	32.04	1.35 (at 18 °C)	–	–	–	–	Weakly basic. Gives creatinine on heating with dilute acids	Cell constituent. Creatine phosphate acts as store of 'phosphate bond energy' in vertebrate muscle (see page 437)
Creatinine (1-methylglyco-cyamidine)	$C_4H_7N_3O$ 113.12	$HN{=}C{\cdot}N(CH_3){\cdot}CH_2{\cdot}CO$ (ring closed through NH)	42.47	6.24	37.15	8.7 (at 16 °C)	–	–	–	–	Strongly basic	Present in urine

Cystathionine	$C_7H_{14}N_2O_4S$ 222.26	HOOC CH(NH$_2$) CH$_2$ S CH$_2$ CH$_2$ CH(NH$_2$) COOH	37.83	6.35	12.60 Sulphur 14.43	–	22	1.0	1-N HCl	+ 23.7	–	Intermediate in transsulphuration of methionine with serine (see page 398)
Cysteic acid	$C_3H_7NO_5S$ 169.16	HO$_3$S CH$_2$ CH(NH$_2$) COOH	21.30	4.17	8.28 Sulphur 18.96	–	28	6.0	Water	+ 7.8	–	Intermediate in formation of taurine, a bile constituent (see below), from cysteine
Ergothioneine (betaine of thiolhistidine)	$C_9H_{15}N_3O_2S$ 229.30		47.14	6.59	18.33 Sulphur 13.98	–	21	5.0	Water	+116.0	Basic. Stable to alkalis, thiol group is readily oxidized to sulphate under acid conditions. Gives reddish purple colour with diazotized sulphanilic acid and alkali	Occurs in erythrocytes, liver, kidney, other tissues, and in urine and semen[4]. Constituent of ergot
Glycocyamine (guanidinoacetic acid)	$C_3H_7N_3O_2$ 117.11	HN=C(NH$_2$) NH CH$_2$ COOH	30.77	6.03	35.88	Slightly soluble	–	–	–	–	–	In urine. Formed in kidney from arginine and glycine. Precursor of creatine and creatinine (see page 437)
Homoserine (α-amino-γ hydroxy-n butyric acid)	$C_4H_9NO_3$ 119.12	HO CH$_2$ CH$_2$ CH(NH$_2$) COOH	40.33	7.62	11.76	–	24 to 26	0.25	5-N HCl	+ 18.3	–	Intermediate in methionine and homocysteine metabolism (see pages 397–398)
1-Methylhistidine	$C_7H_{11}N_3O_2$ 169.18		49.70	6.55	24.84	20	18	3.72	Water	– 26	–	Free acid isolated from normal urine[7]. In combination with β-alanine forms the dipeptide anserine found in animal muscle[8]
3-Methylhistidine	$C_7H_{11}N_3O_2$ 169.18		49.70	6.55	24.84	–	26	–	Water	– 25.4 to – 26.5	–	Isolated from normal urine[9]
Ornithine (2,5-diamino-n-valeric acid)	$C_5H_{12}N_2O_2$ 132.16	NH$_2$ (CH$_2$)$_3$ CH(NH$_2$) COOH	45.44	9.15	21.20	Very soluble	20	0.84	0.45-N HCl	+ 14.1	Formed from arginine by alkaline hydrolysis	Intermediate in ornithine cycle of urea synthesis (see pages 442–443). Benzoic acid is excreted by the fowl as N,N′-dibenzoylornithine
Taurine (2-aminoethane-sulphonic acid)	$C_2H_7NO_3S$ 125.15	NH$_2$ CH$_2$ CH$_2$ SO$_3$H	19.20	5.64	11.19 Sulphur 25.62	8.78 (at 20°C)	–	–	–	–	–	In muscle tissue of invertebrates. Formed in mammalian liver from cysteine (see page 438). Component of taurocholic acid (bile acid)

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[4] Ratner et al., *J biol Chem*, 204, 95 (1953)
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[6] For review see Bell, D J, *Ann Rep Progr Chem*, 52, 285 (1955)
[7] Searle and Westall, *Biochem J*, 48, 1 (1951)
[8] Long, C. (Ed), *Biochemists' Handbook*, Spon, London, 1961, page 668.
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Nucleosides and nucleotides

A *nucleoside* is a sugar linked to a heterocyclic base. A *nucleotide* is a nucleoside in which the sugar is esterified with phosphoric acid.

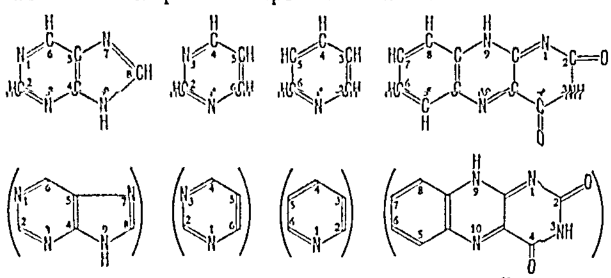
| base | – – | sugar |

Nucleoside

| base | --- | sugar | --- | phosphate |

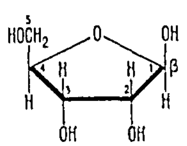
Nucleotide

The bases found in nucleosides and nucleotides are most commonly purines and pyrimidines. Others include pyridines and isoalloxazines. The parent compounds of these bases are:

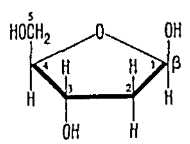


Purine Pyrimidine (1,3-diazine) Pyridine Isoalloxazine

The sugars found in nucleosides and nucleotides are most commonly either ribose or 2-deoxyribose:

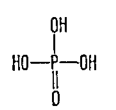


Ribose
(β-D-ribofuranose)

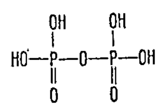


2-Deoxyribose
(β-D-2-deoxyribofuranose)

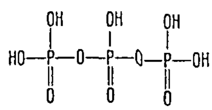
The base–glycoside linkage of nucleosides and nucleotides occupies the 9-position in the case of purines and the 3-position in the case of pyrimidines. Esterification of nucleosides is not confined to orthophosphoric acid. It occurs also with pyrophosphoric (diphosphoric) acid and triphosphoric acid.



Orthophosphoric acid
(monophosphoric acid)



Pyrophosphoric acid
(diphosphoric acid)



Triphosphoric acid

The nomenclature of the nucleosides and nucleotides i: strated by the examples given in Table 9 opposite.

The naturally occurring nucleoside mono-, di- and triph have the sugar–phosphate ester linkage in the 5′-positior tions are the nucleoside 3′-monophosphates and the nı 3′,5′-diphosphates formed during enzymatic digestion nucleic acids. In the case of certain coenzymes, a nucleos: diphosphate or nucleoside 3′,5′-diphosphate structure is countered (see Table 12, pages 344–350).

Nucleotides and polynucleotides (see Nucleic acids, pag 354) occur in all living cells. Certain naturally occurrin nucleosides and nucleotides have no known function ap: being intermediates in the synthesis or breakdown of o cleotides (Tables 10a, b, c, pages 338–342).

Nucleoside di- or triphosphates are precursors of the acids. They act also as carriers of the free energy of pyropł bonds. In this capacity, nucleotides may be regarded as co of the free-energy transfer that occurs in many synth degradative reactions. Nucleoside diphosphates are form the corresponding monophosphates by nucleoside mo phate kinase. This enzyme is analogous in action to a kinase and catalyses the general reaction[1]:

nucleoside monophosphate + adenosine triphospha

⇅

nucleoside diphosphate + adenosine diphosphat

Nucleoside triphosphates are formed in turn from the sponding diphosphates by nucleoside diphosphate kinase[1]

nucleoside diphosphate + adenosine triphospha

⇅

nucleoside triphosphate + adenosine diphosphat

A list of nucleoside mono-, di- and triphosphates and thei tions is given in Table 11, page 343.

The nucleotide coenzymes act as carriers of hydrogen hydrogenases) and as carriers of the active forms of sugars, acids, fatty acids, dicarboxylic acids, carbon dioxide, and su The roles and modes of formation of nucleotide coenzyr listed in Table 12, pages 344–350.

References

[1] LIEBERMAN et al., *J. biol. Chem.*, 215, 429 (1955); GIBSON et al., *Bioch phys. Acta (Amst.)*, 21, 86 (1956).

9 Nomenclature of nucleosides and nucleotides

The group names are the names which can be applied to any compound of the type shown In general the terms nucleoside and nucleotide are

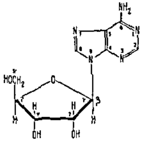
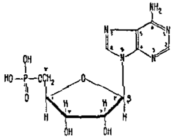
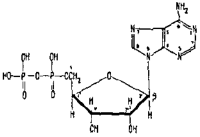
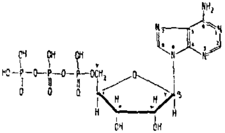
Structural formula	Group name	Alternative group name	Specific name	Specific alternatives
	Nucleoside	Ribonucleoside (ribosylbase)	Adenosine	Ribosyladenine
	Nucleotide (nucleoside mono-phosphate)	Ribonucleotide (ribosylbase mono-phosphate)	5′-Adenylic acid (AMP)	Adenosine 5′-phosphate (adenosine monophos-phate) Adenine nucleotide Ribosyladenin 5′-phosphat
	Nucleoside diphosphate	Ribosylbase diphosphate	Adenosine diphosphate (ADP)	Adenosine 5′-pyro-phosphate
	Nucleoside triphosphate	Ribosylbase triphosphate	Adenosine triphosphate (ATP)	

Table 10a Compounds involved in the biosynthesis and breakdown of purine and pyrimidine nucleotides: Purines and pyrimidin

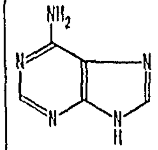
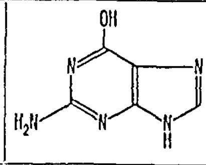
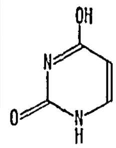
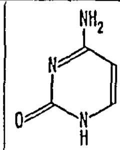
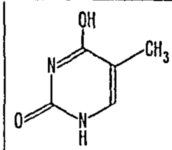
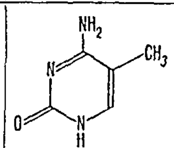
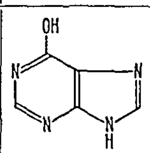
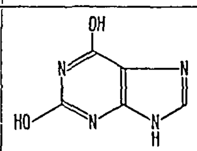
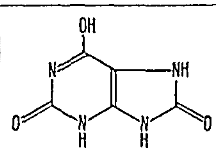
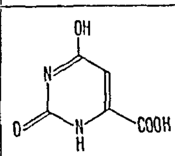
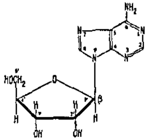
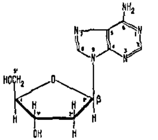
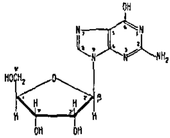
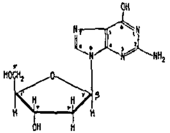
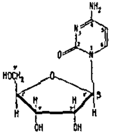
Name	Formula and mol.wt.	Structure	Properties	Occurrence	Function
Adenine (6-amino-purine)	$C_5H_5N_5$ 135.13		m.p. 365 °C (decomp.); picrate 298 °C	Occurs in tea, sugar beet, yeast, various animal organs	These bases are the pro- ucts of the degradation the corresponding nucle- tides. They are further d graded by the pathwa shown on pages 399–40 In mammals only adeni can be converted back t the corresponding nucl otide under normal co ditions but the extent t which this occurs is un certain
Guanine (2-amino-6-hydroxy-purine)	$C_5H_5N_5O$ 151.13		m.p. 365 °C (decomp.); picrate 258–260 °C	Occurs in scales and flesh of fish	
Uracil (2,6-dihy-droxypyrimi-dine)	$C_4H_4N_2O_2$ 112.09		m.p. 338 °C (decomp.)	–	
Cytosine (6-amino-2-hydroxy-pyrimidine)	$C_4H_5N_3O$ 111.10		m.p. 320–325 °C (decomp.); picrate 333 °C	–	
Thymine (2,6-dihy-droxy-5-methyl-pyrimidine)	$C_5H_6N_2O_2$ 126.12		m.p. 321–325 °C	–	
5-Methyl-cytosine (5-methyl-6-amino-2-hydroxy-pyrimidine)	$C_5H_7N_3O$ 125.13		m.p. 270 °C (decomp.); picrate 290–291 °C	Occurs in calf thymus nucleic acid and wheat germ deoxyribonucleic acid	–
Hypoxanthine (6-hydroxy-purine)	$C_5H_4N_4O$ 136.11		m.p. 150 °C (decomp.); picrate 246 °C	Occurs in muscle, meat extracts, blood, urine (the latter especially in leukaemia)	Product of deamination of adenine; precursor of xanthine
Xanthine (2,6-dihy-droxypurine)	$C_5H_4N_4O_2$ 152.11		m.p. 262–264 °C (perchlorate)	Occurs in small quantities in plants, blood, liver, urine, yeast. Component of butterfly pigments and rare urinary calculi	Formed by oxidation of hypoxanthine, or by deamination of guanine; precursor of uric acid
Uric acid (2,6,8-tri-hydroxy-purine)	$C_5H_4N_4O_3$ 168.11		m.p. > 400 °C (decomp.) d^{25} 1.836	Occurs in urine and renal and urinary calculi (increased in urine and blood in gout, leukaemia, nephritis, pneumonia). Also in faeces of birds and reptiles	Formed by oxidation of xanthine. Chief product of nitrogen excretion in reptiles and birds. In mammals other than primates further degraded to allantoin (see page 400)
Orotic acid (2,6-dihy-droxypyrimi-dine-4-car-boxylic acid)	$C_5H_4N_2O_4$ 156.10		m.p. 345–347 °C (decomp.); ethyl ester 200 °C	Occurs in milk	Precursor of orotidylic acid (see pages 438–439)

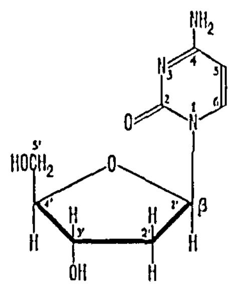
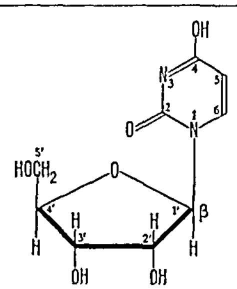
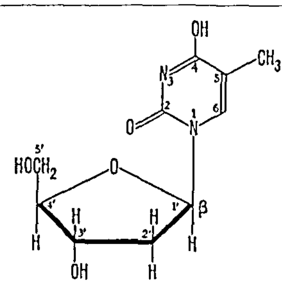
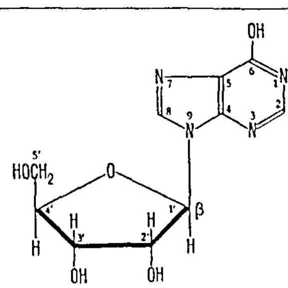
Table 10b Compounds involved in the biosynthesis and breakdown of purine and pyrimidine nucleotides: Nucleosides

The purine nucleosides listed in this table all contain 9-*N* β-riboside or -deoxyriboside linkages, the pyrimidine nucleosides 3-*N* β-ribosid -deoxyriboside linkages. For explanation of the nomenclature see Table 9, page 337.

Name*	Formula and mol.wt	Structure	Specific rotation	Function in mammalian tissue
Adenosine (Ado, A) (ribosyladenine)	$C_{10}H_{13}N_5O_4$ 267.25		$[\alpha]_D^{20}$ − 67.3° (0 1-N NaOH)	These nucleosides are pro ucts of the enzymic hydroly of the corresponding 3′- a 5′-nucleotides The nucle sides in turn are broken do further by phosphorolysis yield ribose 1-phosphate deoxyribose 1-phosphate a the corresponding base N cleoside kinases that form nucleotides from nucleosi plus ATP are known to occ in yeast and in some anin tissues Their importance mammals has not at pres been assessed
Deoxyadenosine (deoxyribosyl-adenine)	$C_{10}H_{13}N_5O_3$ 251.25		$[\alpha]_D^{21}$ − 26°	
Guanosine (Guo, G) (ribosylguanine)	$C_{10}H_{13}N_5O_5$ 283 25		$[\alpha]_D^{20}$ − 60° (2% solution)	
Deoxyguanosine (deoxyribosyl-guanine)	$C_{10}H_{13}N_5O_4$ 267 25		$[\alpha]_D^{19}$ − 47 7° (1-N NaOH)	
Cytidine (Cyd, C) (ribosylcytosine)	$C_9H_{13}N_3O_5$ 243 22		$[\alpha]_D^{20}$ + 29 6°	

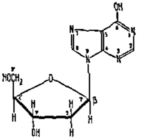
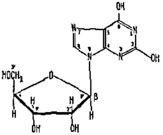
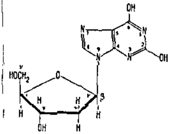
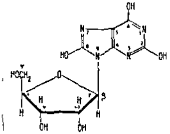
* The three-letter symbols are those recommended by the Combined Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry (*J biol Chem*, 241, 527 (1966)) Other symbols are Thd or T for ribosylthymine a Ψrd or Ψ for 5-ribosyluridine (pseudouridine) Deoxy compounds can indicated by the prefix d (for example dAdo or dA for deoxyadenosine)

Table 10b (continued) Compounds involved in the biosynthesis and breakdown of purine and pyrimidine nucleotides: Nucleosi

Name*	Formula and mol.wt.	Structure	Specific rotation	Function in mammalian t
Deoxycytidine (deoxyribosyl-cytosine)	$C_9H_{13}N_3O_4$ 227.22		$[\alpha]_D^{25}$ + 40°	
Uridine (Urd, U) (ribosyluracil)	$C_9H_{12}N_2O_6$ 244.21		$[\alpha]_D^{16}$ + 9.6°	These nucleosides are ucts of the enzymic hydr of the corresponding 3′ 5′-nucleotides. The nu sides in turn are broken further by phosphoroly yield ribose 1-phosphat deoxyribose 1-phosphate the corresponding base. cleoside kinases that for nucleotides from nucleo plus ATP are known to c in yeast and in some an tissues. Their importanc mammals has not at pre been assessed
Deoxythymidine (deoxyribosyl-thymine)	$C_{10}H_{14}N_2O_5$ 242.23		$[\alpha]_D^{16}$ + 32.50° (1-N NaOH)	
Inosine (Ino, I) (ribosyl-hypoxanthine)	$C_{10}H_{12}N_4O_5$ 268.23		$[\alpha]_D^{18}$ − 72.45° (0.1-N NaOH)	This nucleoside has no kno function other than its rol intermediate in the synth or breakdown of nucleoti (see page 400)

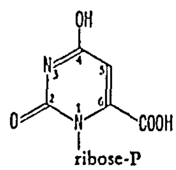
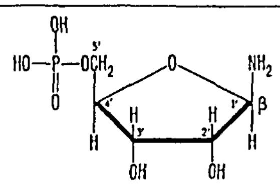
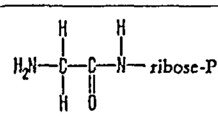
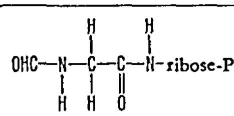
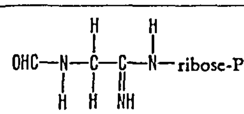
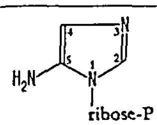
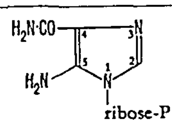
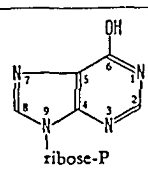
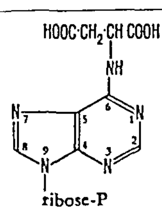
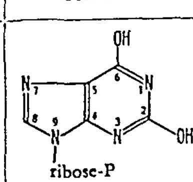
* See footnote page 339.

Table 10b (concluded) Compounds involved in the biosynthesis and breakdown of purine and pyrimidine nucleosides: Nucleosides

Name*	Formula and mol.wt.	Structure	Specific rotation	Function in mammalian tissues
Deoxyinosine (deoxyribosyl-hypoxanthine)	$C_{10}H_{12}N_4O_4$ 252.23		$[\alpha]_D^{18}$ −22.9° (1-N NaOH)	These nucleosides hav known function other their role as intermedia the synthesis or breakdo nucleotides (see page 40
Xanthosine (Xao, X) (ribosylxanthine)	$C_{10}H_{12}N_4O_6$ 284 23		$[\alpha]_D^{20}$ −51 21°	
Deoxyxanthosine (deoxyribosyl-xanthine)	$C_{10}H_{12}N_4O_5$ 268.23		–	
Ribosyluric acid	$C_{10}H_{12}N_4O_7$ 300 23		$[\alpha]_D^{20}$ −40 8° (0 1-N NaOH)	

* See footnote page 339

Table 10c Compounds involved in the biosynthesis and breakdown of purine and pyrimidine nucleotides: Nucleotides
With the exception of inosinic acid, the compounds listed here have no known coenzyme activity.

Name	Formula and mol.wt.	Structure*	Function
Orotidylic acid (OMP) (ribosylorotic acid 5′-phosphate)	$C_{10}H_{13}N_2O_{11}P$ 368.20		Intermediate in biosynthesis of pyrimidine nucl tides. Formed from orotic acid (see pages 438–4
5-Phosphoribosyl-amine (D-ribosylamine 5′-phosphate)	$C_5H_{12}NO_7P$ 229.13		
Ribosylglycinamide 5′-phosphate	$C_7H_{15}N_2O_8P$ 286.18		
Ribosylformyl-glycinamide 5′-phosphate	$C_8H_{15}N_2O_9P$ 314.19		Intermediates in biosynthesis of inosinic acid (s pages 433 and 435)
Ribosylformyl-glycinamidine 5′-phosphate	$C_8H_{16}N_3O_8P$ 313.21		
1-Ribosyl-5-amino-imidazole 5′-phosphate	$C_8H_{14}N_3O_7P$ 295.19		
1-Ribosyl-5-amino-imidazole-4-carboxamide 5′-phosphate	$C_9H_{15}N_4O_8P$ 338.22		
Inosinic acid (IMP) (inosine 5′-phosphate)	$C_{10}H_{13}N_4O_8P$ 348.21		Precursor of adenosine 5′-phosphate (AMP) anc guanosine 5′phosphate (GMP) (see Table 11, pag 343). Can partially replace certain coenzyme func tions of other nucleotides
Succinyladenylic acid (succinyl-adenosine 5′-phosphate)	$C_{14}H_{18}N_5O_{11}P$ 463.30		Intermediate in synthesis of adenosine 5′-phosphate (AMP) from inosinic acid (see pages 435–436)
Xanthylic acid (XMP) (xanthosine 5′-phosphate)	$C_{10}H_{13}N_4O_9P$ 364.21		Intermediate in synthesis of guanosine 5′-phosphate (GMP) from inosinic acid (see page 436)

* For structure of the 'ribose-P' portion of the molecule see Table 9, page 337.

ble 11 Nucleoside 5′-mono-, di- and triphosphates (5′-nucleotides)

Name	Abbreviation	Formula	Mol.wt.	Function
Adenosine monophosphate (adenylic acid)	AMP	$C_{10}H_{14}N_5O_7P$	347.23	Precursor of ADP. Activates phosphoryla
Adenosine diphosphate	ADP	$C_{10}H_{15}N_5O_{10}P_2$	427.21	Immediate precursor of polynucleotides. other functions see page 404
Adenosine triphosphate	ATP	$C_{10}H_{16}N_5O_{13}P_3$	507.19	Precursor of adenosine coenzymes (see Tabl pages 344–346). For other functions see page
Deoxyadenosine monophosphate	dAMP	$C_{10}H_{14}N_5O_6P$	331.23	Precursor of deoxyadenosine diphosphate
Deoxyadenosine diphosphate	dADP	$C_{10}H_{15}N_5O_9P_2$	411.21	Precursor of deoxyadenosine triphosphate
Deoxyadenosine triphosphate	dATP	$C_{10}H_{16}N_5O_{12}P_3$	491.19	Immediate precursor of deoxyribosepolynuc tides
Guanosine monophosphate (guanylic acid)	GMP	$C_{10}H_{14}N_5O_8P$	363.23	Precursor of guanosine diphosphate
Guanosine diphosphate	GDP	$C_{10}H_{15}N_5O_{11}P_2$	443.21	Immediate precursor of polynucleotides Yi guanosine triphosphate during cleavage of s cinyl-coenzyme A
Guanosine triphosphate	GTP	$C_{10}H_{16}N_5O_{14}P_3$	523.19	Precursor of guanosine coenzymes (see Ta 12, page 347). Formed from orthophospl and guanosine diphosphate during cleavag succinyl-coenzyme A
Deoxyguanosine monophosphate (desoxyguanylic acid)	dGMP	$C_{10}H_{14}N_5O_7P$	347.23	Precursor of deoxyguanosine diphosphate
Deoxyguanosine diphosphate	dGDP	$C_{10}H_{15}N_5O_{10}P_2$	427.21	Precursor of deoxyguanosine triphosphate
Deoxyguanosine triphosphate	dGTP	$C_{10}H_{16}N_5O_{13}P_3$	507.19	Immediate precursor of deoxyribosepolynuc tides
Cytidine monophosphate (cytidylic acid)	CMP	$C_9H_{14}N_3O_8P$	323.20	Precursor of cytidine diphosphate
Cytidine diphosphate	CDP	$C_9H_{15}N_3O_{11}P_2$	403.18	Immediate precursor of polynucleotides Precursor of cytidine triphosphate
Cytidine triphosphate	CTP	$C_9H_{16}N_3O_{14}P_3$	483.16	Precursor of cytidine coenzymes (see Tabl pages 349–350)
Deoxycytidine monophosphate (deoxycytidylic acid)	dCMP	$C_9H_{14}N_3O_7P$	307.20	Precursor of deoxycytidine diphosphate
Deoxycytidine diphosphate	dCDP	$C_9H_{15}N_3O_{10}P_2$	387.18	Precursor of deoxycytidine triphosphate
Deoxycytidine triphosphate	dCTP	$C_9H_{16}N_3O_{13}P_3$	467.16	Immediate precursor of deoxyribosepolynuc tides
Uridine monophosphate (uridylic acid)	UMP	$C_9H_{13}N_2O_9P$	324.19	Precursor of uridine diphosphate
Uridine diphosphate	UDP	$C_9H_{14}N_2O_{12}P_2$	404.17	Immediate precursor of polynucleotides Precursor of uridine triphosphate
Uridine triphosphate	UTP	$C_9H_{15}N_2O_{15}P_3$	484.15	Precursor of uridine coenzymes (see Tabl pages 347–349)
Deoxythymidine monophosphate (thymidylic acid)	dTMP	$C_{10}H_{15}N_2O_8P$	322.21	Precursor of deoxythymidine diphosphate
Deoxythymidine diphosphate	dTDP	$C_{10}H_{16}N_2O_{11}P_2$	402.19	Precursor of deoxythymidine triphosphate
Deoxythymidine triphosphate	dTTP	$C_{10}H_{17}N_2O_{14}P_3$	482.17	Immediate precursor of deoxyribosepolynu tides
Deoxy-5-hydroxymethylcytidine monophosphate	dHMCMP	$C_{10}H_{16}N_3O_8P$	337.23	Constituent nucleotide of the deoxyribonu acid of T_2, T_4 and T_6 bacteriophages of *Esche coli*, in which it replaces deoxycytidine m phosphate
Deoxy-5-methylcytidine monophosphate	dMCMP	$C_{10}H_{16}N_3O_7P$	321.23	Constituent of the deoxyribonucleic aci wheat germ, in which it partially replace

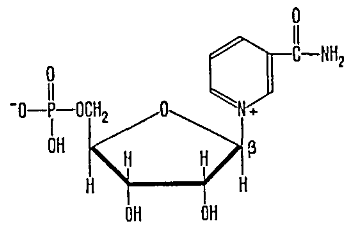
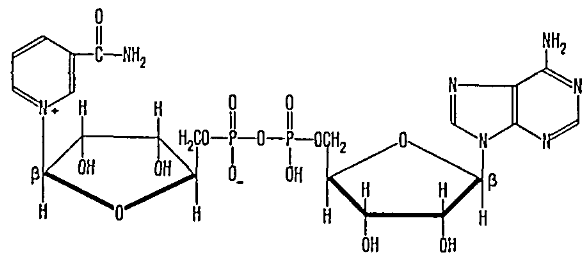
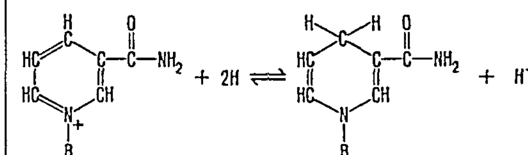
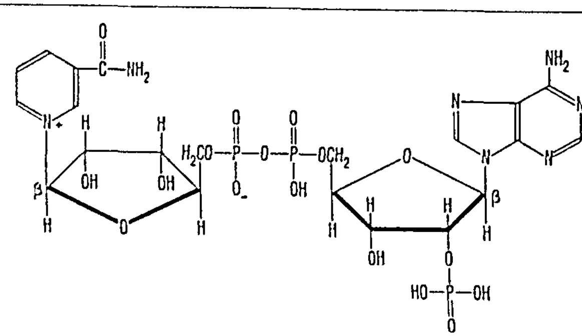
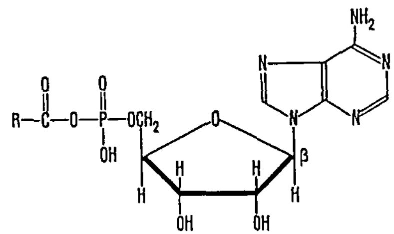
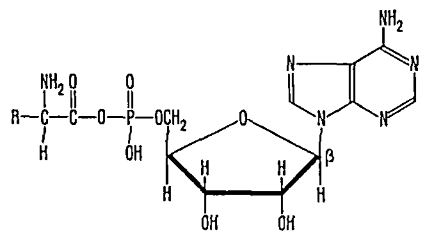
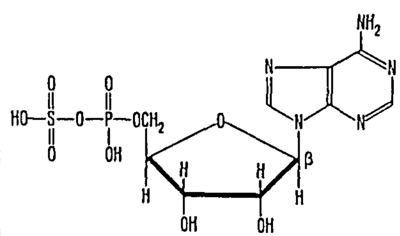
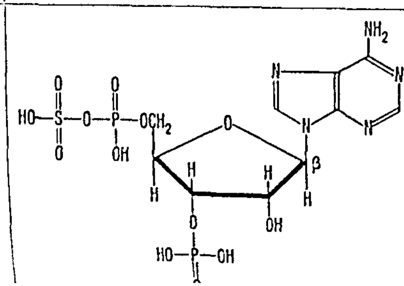
Name	Formula and mol.wt.	Structure	Functions	Reference (see page 350)
Nicotinamide mononucleotide (NMN)	$C_{11}H_{15}N_2O_8P$ 334.22		Constituent of nicotinamide-adenine dinucleotide (NAD) and nicotinamide-adenine dinucleotide phosphate (NADP) (see below)	7
Nicotinamide-adenine dinucleotide (NAD) (diphosphopyridine nucleotide, DPN; codehydrogenase I; coenzyme I, Co I; cozymase)	$C_{21}H_{27}N_7O_{14}P_2$ 663.44		Formed by the reaction: nicotinamide mononucleotide + ATP → NAD + pyrophosphate. Coenzyme of many dehydrogenases, in which function the pyridine ring of the molecule is reduced reversibly as follows: 	7
Nicotinamide-adenine dinucleotide phosphate (NADP) (triphosphopyridine nucleotide, TPN; codehydrogenase II; coenzyme II, Co II; phosphocozymase)	$C_{21}H_{28}N_7O_{17}P_3$ 743.42		Formed by the reaction: NAD + ATP → NADP + ADP. Coenzyme of many dehydrogenases, in which function the pyridine ring of the molecule is reduced reversibly as shown above	7

Table 12 (continued) Nucleotides with coenzyme functions

Name	Formula and mol.wt.	Structure	Functions	Reference (see page 350)
Acyl adenosine monophosphates (acyl-adenylates)	–	 where R = $CH_3 \cdot (CH_2)_n$—	Formed by the reaction: fatty acid + ATP → acyl adenosine monophosphate + pyrophosphate. Intermediate in activation of acetic acid and other fatty acids (page 391)	4
Aminoacyl adenosine monophosphates	–	 where R = amino-acid residue	Intermediate in activation of amino acids for protein synthesis	5
Adenosine 5′-phosphosulphate	$C_{10}H_{14}N_5O_{10}PS$ 427.29		Formed from ATP and inorganic sulphate. Intermediate in sulphate ester synthesis (see page 445)	6
Adenosine 3′-phosphate 5′-phosphosulphate	$C_{10}H_{15}N_5O_{13}P_2S$ 507.27		Formed from adenosine 5′-phosphosulphate and ATP. Donor of sulphate group in formation of esters of sulphuric acid (see page 445)	6

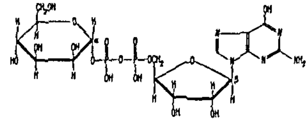
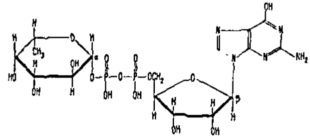
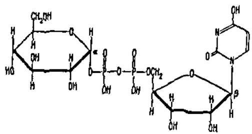
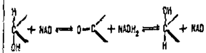
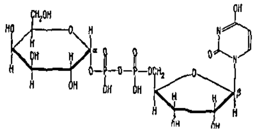
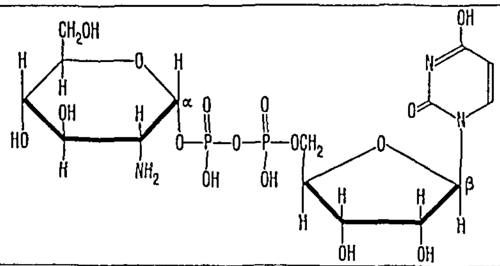
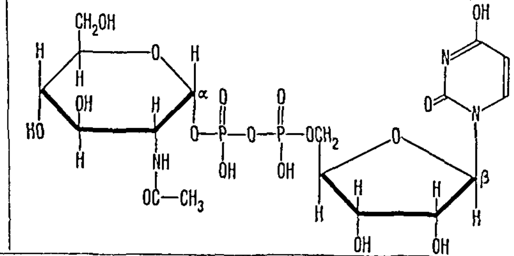
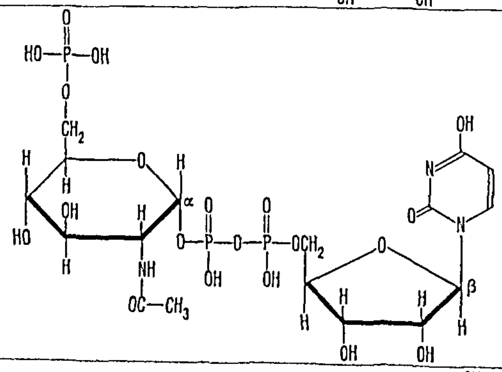
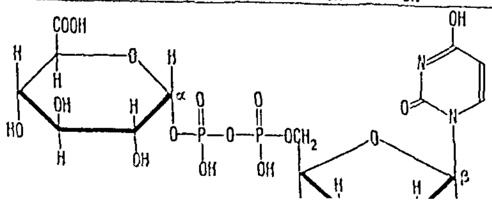
	Probably intermediate in interconversions involving mannose. Formed from mannose 1-phosphate and guanosine triphosphate	7
	Naturally occurring precursor of L-fucose and form in which L-fucose is incorporated into milk oligosaccharides and probably other glycoproteins	[illegible]
	Formed by the reaction: glucose 1-phosphate + UTP → uridine diphosphate glucose + pyrophosphate. Precursor of uridine diphosphate glucuronic acid (see page 348). Intermediate in interconversion of glucose and galactose, uridine diphosphate glucose $\overset{NAD}{\rightleftharpoons}$ uridine diphosphate galactose. In this reaction NAD is required for the consecutive oxidation and reduction of the 4-position of the hexose ring: 	[illegible]
	Intermediate in interconversion of galactose and glucose (see under 'Uridine diphosphate glucose' above). Probable intermediate in formation of lactose	[illegible]

Table 12 (continued) Nucleotides with coenzyme functions

Name	Formula and mol.wt.	Structure	Functions	Reference (see page 350)
Uridine diphosphate glucosamine	$C_{15}H_{25}N_3O_{16}P_2$ 565.32		Intermediate in synthesis of mucopolysaccharides. Formed from uridine triphosphate and glucosamine 1-phosphate	*10*
Uridine diphosphate *N*-acetyl-glucosamine	$C_{17}H_{27}N_3O_{17}P_2$ 607.36		Intermediate in synthesis of mucopolysaccharides and glycoproteins	*11*
Uridine diphosphate acetylglucosamine phosphate	$C_{17}H_{28}N_3O_{20}P_3$ 687.34		Intermediate in synthesis of mucopolysaccharides and glycoproteins	*12*
Uridine diphosphate glucuronic acid	$C_{15}H_{22}N_2O_{18}P_2$ 580.29		Formed from uridine diphosphate glucose by NAD-dependent oxidation. Donor of glucuronic acid in formation of glucuronide detoxication products, and probably also in formation of polysaccharides containing glucuronic acid (see page 423)	*13*

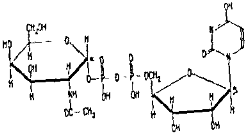
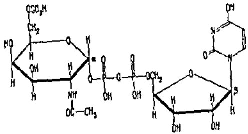
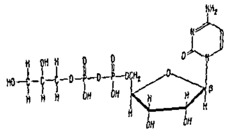
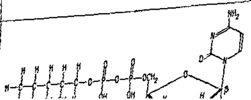
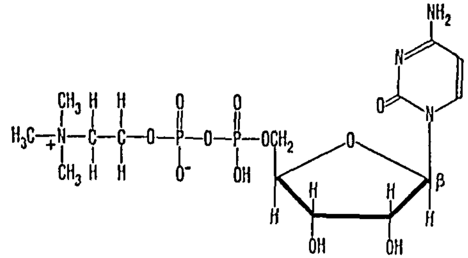
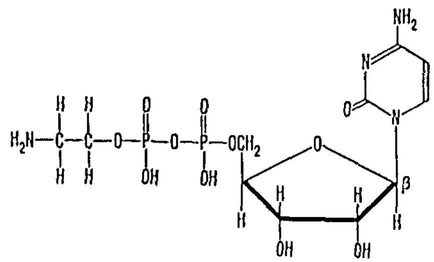
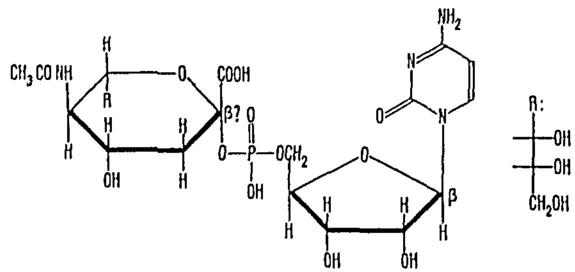
Uridine diphosphate *N* acetyl galactosamine	$C_{17}H_{27}N_3O_{17}P_2$ 607 36	
Uridine diphosphate *N* acetyl-galactosamine sulphate	$C_{17}H_{27}N_3O_{20}P_2S$ 687 42	
Cytidine diphosphate glycerol	$C_{12}H_{21}N_3O_{13}P_2$ 477 26	
Cytidine diphosphate ribitol	$C_{14}H_{25}N_3O_{15}P_2$ 537 31	

Table 12 (concluded) Nucleotides with coenzyme functions

Name	Formula and mol.wt.	Structure	Functions	Reference
Cytidine diphosphate choline	$C_{14}H_{26}N_4O_{11}P_2$ 488.33		Formed from cytidine triphosphate and phosphorylcholine. Involved in formation of lecithin: cytidine diphosphate choline + α,β-diglyceride → lecithin + cytidine monophosphate (see page 425)	17
Cytidine diphosphate ethanolamine	$C_{11}H_{20}N_4O_{11}P_2$ 446.25		Formed from cytidine triphosphate and phosphorylethanolamine. Involved in formation of cephalin (phosphatidylethanolamine) (see page 425)	17
Cytidine monophosphate *N*-acetylneuraminic acid	$C_{20}H_{31}N_4O_{16}P$ 614.46		Intermediate in incorporation of *N*-acetylneuraminic acid into milk oligosaccharides and other glycoproteins	18

References

1 Racker, E., *Physiol. Rev.*, 35, 1 (1955).
2 White et al., *Principles of Biochemistry*, London, McGraw-Hill, 1954.
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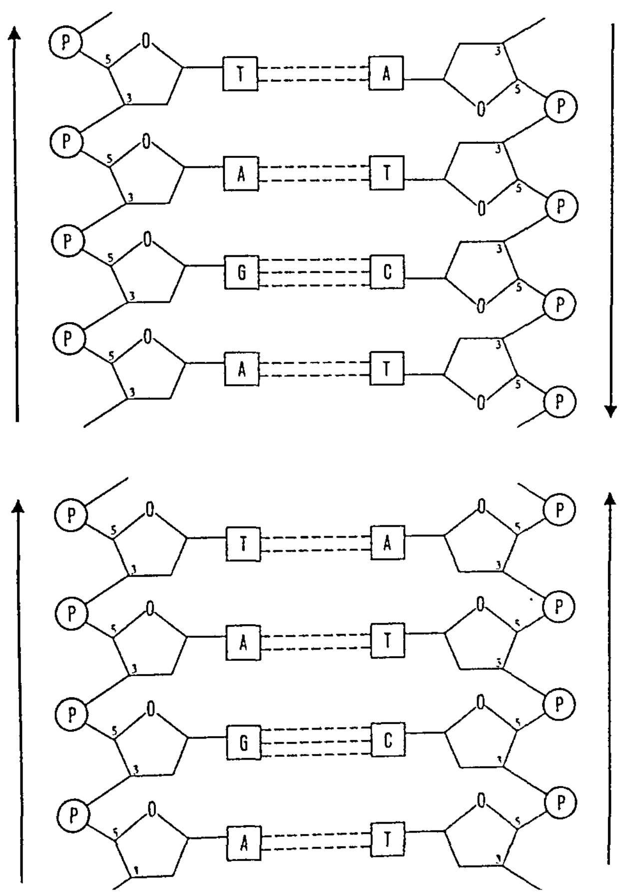
$$x\text{dATP} + x\text{dTTP} + y\text{dGTP} + y\text{dCTP} \underset{\text{DNA primer}}{\overset{Mg^{++}}{\rightleftharpoons}} \text{DNA} + (2x+2y)\text{pyrophosphate}$$

The enzyme has an absolute requirement for magnesium ions as well as for a 'primer' consisting of DNA. It requires all four deoxyribonucleotides if a primer containing all four deoxyribonucleotides is used. The enzyme is specific for the four *deoxyribo*nucleoside *tri*phosphates. Mono- and diphosphates are inactive, as are all ribonucleotides[1,2].

The base composition of the enzymatically formed DNA is a complementary copy of the base composition of the DNA used as primer, regardless of the relative amounts of each deoxyribonucleoside triphosphate added to the reaction mixture[3]. This and other evidence[4] shows that the enzymatic synthesis occurs by 'base-pairing' with the primer DNA. In other words, the role of the primer DNA is that of a DNA template. Where the DNA template contains the base adenine, the nucleotide inserted into the new molecule is the base thymine, and vice versa. Where the template contains the base guanine, the nucleotide inserted into the new molecule is cytosine, and vice versa[2]. Such assembly can occur in two directions. In one direction the newly synthesized molecule of DNA has *opposite polarity* to the template molecule, i.e., the 3',5'-phosphodiester bridges in the template point in the opposite direction to the 3',5'-phosphodiester bridges of the newly synthesized molecule. In the other direction the newly synthesized molecule of DNA has *similar polarity*. Here the 3',5'-phosphodiester bridges of template DNA and newly formed DNA point in the same direction (Fig. 5). Experimental evidence shows that the newly synthesized DNA has the *opposite* polarity of the template. The product is double-stranded DNA. When the primer is double-stranded DNA it must presumably be 'unwound' into single-strand DNA before it can act as a template for DNA synthesis. The mechanism for such 'unwindi[ng]' is not understood, but one possibility is that the 'unwinding' oc[curs] just ahead of the growth of the new DNA chain[5].

Fig. 5 Double-stranded DNA of opposite polarity (upper diagram) and of similar polarity (lower diagram). Experimental evidence shows that during the synthesis of DNA the new strand is of opposite polarity[4]

$\boxed{A}$ Adenine; $\boxed{T}$ Thymine; $\boxed{G}$ Guanine; $\boxed{C}$ Cytosine; $\boxed{P}$ Phosphate



Using pure DNA polymerase, the total synthesis of infect[ious] viral DNA starting from the four deoxynucleoside triphosph[ates] has been accomplished in vitro[6].

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[1] Lehman et al., *J.biol.Chem.*, 233, 163 (1958); Bessman et al., *J.biol.Ch[em.]*, 233, 171 (1958); Adler et al., *Proc.nat.Acad.Sci.(Wash.)*, 44, 641 (19[58]); Bollum, F.J., *Fed.Proc.*, 17, 193 (1958); Bollum and Potter, *J.biol.Ch[em.]*, 233, 478 (1958); Kornberg, A., *Harvey Lect. 1957–1958*, 53, 83 (19[59]); Smellie et al., *Biochim.biophys.Acta (Amst.)*, 35, 389 (1959); Smellie et [al.], *Biochim.biophys.Acta (Amst.)*, 37, 243 (1960); Grunberg-Manago, M., *Pr[ogr.] Biophys.molec.Biol.*, 13, 175 (1963).

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Synthesis of RNA

RNA nucleotidyltransferase (RNA polymerase). This enzyme cat[a]lyses the formation of RNA from nucleoside 5'-triphosphates[1]:

$$x(\text{ATP} + \text{GTP} + \text{UTP} + \text{CTP}) \underset{\text{DNA primer}}{\overset{Mn^{++}}{\rightleftharpoons}} \text{RNA} + 4x \text{ pyrophospha[te]}$$

The reaction requires all four ribonucleoside triphosphates and DNA primer. The product is RNA with a base composition th[at] is a complementary copy of the DNA primer[2]. The enzyme re[-]quires a bivalent metal ion, manganese being more effective tha[n] magnesium. The chief physiological function of this enzyme i[s] probably to make messenger RNA for protein synthesis[3], in othe[r] words, to transcribe information contained in the DNA code int[o] RNA ('transcription'). This enzyme is also responsible for the syn[-]thesis of ribosomal RNA and s-RNA[4]. The nature of the RN[A] actually synthesized is determined by specific factors that adap[t] the enzyme to specific template DNA[5].

Other types of RNA polymerases also exist. For example, vi[-]ruses that contain RNA but not DNA can duplicate in host cells. In this case viral RNA acts as the template and DNA is not re[-]quired for the *de novo* synthesis of RNA[6].

Polyribonucleotide nucleotidyltransferase (polynucleotide phospho[-]rylase). This enzyme catalyses the synthesis of polyribonucleotide[s] from nucleoside 5'-diphosphates. The reverse reaction is terme[d] phosphorolysis:

$$x \text{ nucleoside diphosphate} \overset{Mg^{++}}{\rightleftharpoons} \text{RNA} + x \text{ orthophosphate}$$

The RNA formed according to this equation will contain x mono[-]nucleotide units. The enzyme is specific for *ribo*nucleoside *diphos*[-]phates. Nucleoside mono- and triphosphates are inactive; also in[-]active are deoxyribonucleoside diphosphates[7]. The enzyme is rela[-]tively unspecific with respect to the base of the nucleoside diphos[-]phate[8]. It can make polymers containing one or more bases. When the four ribonucleoside diphosphates containing adenine (A), guanine (G), cytidine (C), and uracil (U) are used, an RNA-like polymer results in which the base-sequence is random[9]. The syn[-]thesis of RNA shows a lag period that is abolished if an RNA primer is added[10,11]. When a primer is supplied the enzyme adds new nucleotides to the ends of the primer molecules[11].

The function of this enzyme reaction is not yet understood. Its chief role may be not to synthesize but to degrade RNA. s-RNA is very resistant to phosphorolysis by polynucleotide phosphorylase, but the rapid breakdown of m-RNA may be catalysed by this enzyme[8].

References

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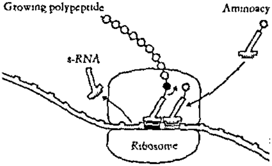
Fig 6 Diagrammatic representation of protein synthesis



Synthesis of proteins[1–3]

Protein synthesis involves the linking together of 20 different amino acids in specific sequences containing hundreds of amino acids The amino-acid sequence of a particular protein is reproduced

into messenger RNA (m-RNA) by an enzyme, RNA polymerase, that requires DNA as a primer This enzyme copies the base sequence of DNA into RNA Each molecule of DNA is thus tran

tural unit of protein synthesis, the ribosome

Amino acids are activated by attachment to another kind of RNA, namely soluble RNA (s RNA, transfer RNA)[5] (see page 351)

$$\underset{\text{acid}}{\text{amino}} + \text{ATP} + \text{s-RNA} \rightleftharpoons \underset{\text{s RNA}}{\textit{aminoacyl}} + \text{AMP} + \underset{\text{phosphate}}{\text{pyro-}}$$

The reaction proceeds through the intermediate formation of aminoacyl AMP For each amino acid there are at least one specific activating enzyme and one specific type of s-RNA Each amino

follows

and aminoacyl s-RNA are brought together This can be pi as shown in Figure 6 above

In Figure 6 the divisions along the m-RNA are inten represent coding information equivalent to one amino acid one new aminoacyl-s-RNA can fit into the ribosomal frame The *specific* kind of aminoacyl s-RNA is determined by the se

reaches the end of the newly synthesized protein molecule th s-RNA must be lost by hydrolysis, but the details of the rele the protein molecule from the ribosome are not clear at pr UAA, UAG and UGA are thought to be the triplets that term polypeptide synthesis[16]

$$\text{H}_2\text{N AA}_1 \text{ CO s-RNA}_1$$

$$\Big\downarrow + \text{H}_2\text{N AA}_m \text{ CO s-RNA}_m$$

$$\text{H}_2\text{N AA}_1 \text{ CO NH AA}_m \text{ CO s-RNA}_m + \text{s-RNA}_1$$

$$\Big\downarrow + \text{H}_2\text{N AA}_x \text{ s-RNA}_x$$

$$\text{H}_2\text{N AA}_1 \text{ CO NH AA}_m \text{ CO NH AA}_x \text{ CO s-RNA}_x + \text{s-RNA}_m$$

$$\Big\downarrow + \text{H}_2\text{N AA}_n \text{ s-RNA}_n$$

$$\text{H}_2\text{N AA}_1 \text{ CO NH AA}_m \text{ CO NH AA}_x \text{ CO NH AA}_n \text{ s-RNA}_n + \text{s-RNA}_x$$

$$\Big\downarrow + \text{H}_2\text{N-AA}_p \text{ s-RNA}_p$$

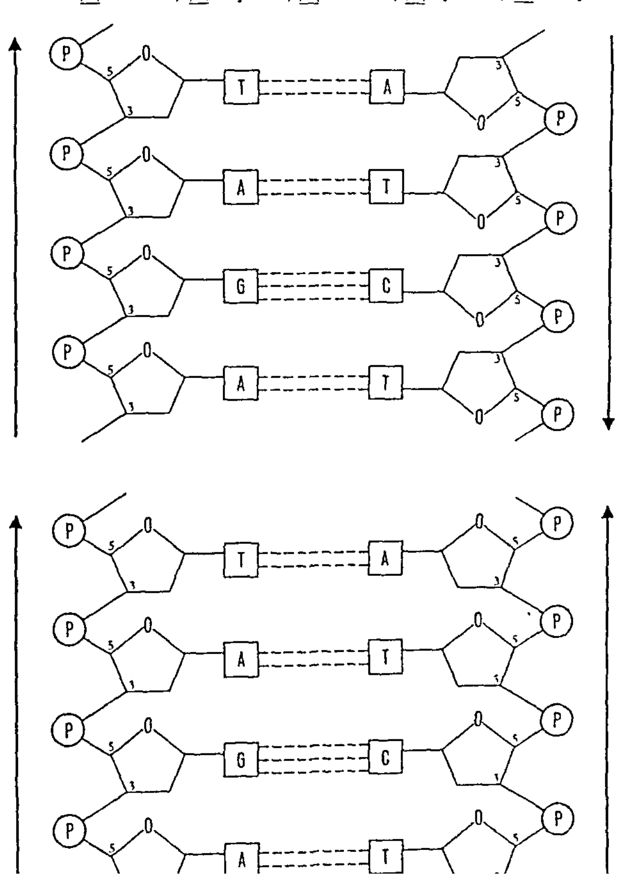
$$x\text{dATP} + x\text{dTTP} + y\text{dGTP} + y\text{dCTP} \underset{\text{DNA primer}}{\overset{Mg^{++}}{\rightleftharpoons}} \text{DNA} + \begin{matrix}(2x+2y)\text{pyro-}\\ \text{phosphate}\end{matrix}$$

The enzyme has an absolute requirement for magnesium ions as well as for a 'primer' consisting of DNA. It requires all four deoxyribonucleotides if a primer containing all four deoxyribonucleotides is used. The enzyme is specific for the four *deoxyribo*nucleoside *tri*phosphates. Mono- and diphosphates are inactive, as are all ribonucleotides[1,2].

The base composition of the enzymatically formed DNA is a complementary copy of the base composition of the DNA used as primer, regardless of the relative amounts of each deoxyribonucleoside triphosphate added to the reaction mixture[3]. This and other evidence[4] shows that the enzymatic synthesis occurs by 'base-pairing' with the primer DNA. In other words, the role of the primer DNA is that of a DNA template. Where the DNA template contains the base adenine, the nucleotide inserted into the new molecule is the base thymine, and vice versa. Where the template contains the base guanine, the nucleotide inserted into the new molecule is cytosine, and vice versa[2]. Such assembly can occur in two directions. In one direction the newly synthesized molecule of DNA has *opposite polarity* to the template molecule, i.e., the 3',5'-phosphodiester bridges in the template point in the opposite direction to the 3',5'-phosphodiester bridges of the newly synthesized molecule. In the other direction the newly synthesized molecule of DNA has *similar polarity*. Here the 3',5'-phosphodiester bridges of template DNA and newly formed DNA point in the same direction (Fig. 5). Experimental evidence shows that the newly synthesized DNA has the *opposite* polarity of the template. The product is double-stranded DNA. When the primer is double-stranded DNA it must presumably be 'unwound' into single-strand DNA before it can act as a

Fig. 5 Double-stranded DNA of opposite polarity (upper diagram) and of similar polarity (lower diagram). Experimental evidence shows that during the synthesis of DNA the new strand is of opposite polarity[4]

[A] Adenine; [T] Thymine; [G] Guanine; [C] Cytosine; [P] Phosphate



template for DNA synthesis. The mechanism for such 'unv
is not understood, but one possibility is that the 'unwind
curs just ahead of the growth of the new DNA chain[5].

Using pure DNA polymerase, the total synthesis of i
viral DNA starting from the four deoxynucleoside triphc
has been accomplished in vitro[6].

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Synthesis of RNA

RNA nucleotidyltransferase (RNA polymerase). This enzyn
lyses the formation of RNA from nucleoside 5'-triphospha

$$x(\text{ATP} + \text{GTP} + \text{UTP} + \text{CTP}) \underset{\text{DNA primer}}{\overset{Mn^{++}}{\rightleftharpoons}} \text{RNA} + 4x \text{ pyrophc}$$

The reaction requires all four ribonucleoside triphosphates
DNA primer. The product is RNA with a base compositic
is a complementary copy of the DNA primer[2]. The enzy
quires a bivalent metal ion, manganese being more effectiv
magnesium. The chief physiological function of this enz
probably to make messenger RNA for protein synthesis[3], ir
words, to transcribe information contained in the DNA coc
RNA ('transcription'). This enzyme is also responsible for tl
thesis of ribosomal RNA and s-RNA[4]. The nature of the
actually synthesized is determined by specific factors that
the enzyme to specific template DNA[5].

Other types of RNA polymerases also exist. For examp
ruses that contain RNA but not DNA can duplicate in host
In this case viral RNA acts as the template and DNA is r
quired for the *de novo* synthesis of RNA[6].

Polyribonucleotide nucleotidyltransferase (polynucleotide phc
rylase). This enzyme catalyses the synthesis of polyribonucle
from nucleoside 5'-diphosphates. The reverse reaction is t
phosphorolysis:

$$x \text{ nucleoside diphosphate} \overset{Mg^{++}}{\rightleftharpoons} \text{RNA} + x \text{ orthophosp}$$

The RNA formed according to this equation will contain x n
nucleotide units. The enzyme is specific for *ribo*nucleoside *di*
phates. Nucleoside mono- and triphosphates are inactive; al
active are deoxyribonucleoside diphosphates[7]. The enzyme is
tively unspecific with respect to the base of the nucleoside di
phate[8]. It can make polymers containing one or more bases.
the four ribonucleoside diphosphates containing adenine
guanine (G), cytidine (C), and uracil (U) are used, an RN
polymer results in which the base-sequence is random[9]. The
thesis of RNA shows a lag period that is abolished if an
primer is added[10,11]. When a primer is supplied the enzyme
new nucleotides to the ends of the primer molecules[11].

The function of this enzyme reaction is not yet understoo
chief role may be not to synthesize but to degrade RNA. s-R
very resistant to phosphorolysis by polynucleotide phosphor
but the rapid breakdown of m-RNA may be catalysed by
enzyme[8].

References

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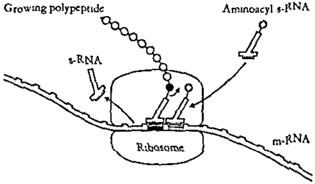
Fig 6 Diagrammatic representation of protein synthesis

Polypeptide s RNA is transferred to the new aminoacyl s RNA. The growing polypeptide s-RNA together with the m RNA then moves along the ribosome from right to left by one division A molecule of s RNA is released



...thesis of proteins[1-3]

...otein synthesis involves the linking together of 20 different ...no acids in specific sequences containing hundreds of amino ... The amino-acid sequence of a particular protein is reproduced ...tly over and over again in each protein molecule synthesized ...ors in amino-acid sequence are exceedingly rare The exact

Amino acids are activated by attachment to another kind of ...NA, namely soluble RNA (s-RNA, transfer-RNA)[8] (see page 351)

$$\text{amino acid} + \text{ATP} + \text{s-RNA} \rightleftharpoons \text{aminoacyl s-RNA} + \text{AMP} + \text{pyrophosphate}$$

The reaction proceeds through the intermediate formation of ...inoacyl AMP For each amino acid there are at least one spe...ic activating enzyme and one specific type of s RNA Each amino ...id activating enzyme thus recognizes ...

...ows

The scheme shows that proteins grow by the stepwise addition

RNA (an 'anticodon' or 'nodoc')[9,10] In bacteria, protein chains (codons AUG, GUG) have been shown to be initiated by formyl-methionyl-s-RNA

The assembly of the polypeptide occurs on the ribosome The function of the ribosome is that of a framework on which m-RNA and aminoacyl-s-RNA are brought together This can be pictured as shown in Figure 6 above

In Figure 6 the divisions along the m-RNA are intended to ...

liberated and dissociates from the ribosome This process requires transfer enzymes[11-13]. The m-RNA and polypeptide s-RNA must now move along the ribosomal framework by one segment, and the process is then repeated When the synthetic mechanism reaches the end of the newly synthesized protein molecule the last ...

$$\mathrm{H_2N\ AA_l\ CO\ s\text{-}RNA_l}$$
$$\Big\downarrow + \mathrm{H_2N\ AA_m\ CO\ s\text{-}RNA_m}$$
$$\mathrm{H_2N\ AA_l \cdot CO\ NH\ AA_m\ CO \cdot s\text{-}RNA_m + s\text{-}RNA_l}$$
$$\Big\downarrow + \mathrm{H_2N \cdot AA_n \cdot s\text{-}RNA_n}$$
$$\mathrm{H_2N\ AA_l\ CO\ NH \cdot AA_m\ CO\ NH \cdot AA_n \cdot CO \cdot s\text{-}RNA_n + s\text{-}RNA_m}$$
$$\Big\downarrow + \mathrm{H_2N \cdot AA_o\ s\text{-}RNA_o}$$
$$\mathrm{H_2N \cdot AA_l\ CO\ NH \cdot AA_m \cdot CO \cdot NH\ AA_n\ CO\ NH \cdot AA_o \cdot s\text{-}RNA_o + s\text{-}RNA_n}$$
$$\Big\downarrow + \mathrm{H_2N\ AA_p \cdot s\text{-}RNA_p}$$

etc.

The transfer of amino acid from aminoacyl-s-RNA to ribosomal polypeptide requires GTP[11,12]. The role of GTP in this reaction is not understood.

Electron microscopy reveals that ribosomes actively engaged in protein synthesis appear like beads strung on a thread[14]. It has also been shown that ribosomes active in protein synthesis have a much higher molecular weight than those not active[15]. This evidence has been interpreted to show that more than one ribosome can be attached to each molecule of m-RNA. The assembly of one molecule of protein starts before the assembly of another, further along the molecule of m-RNA, has been completed.

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Minor (infrequently occurring) constituents of nucleic acids

More than 20 minor purine and pyrimidine nucleosides have been found in hydrolysates of RNA isolated from various organisms. There are several classes of these minor components. In the largest class the bases are methylated. The majority of the theoretically possible methylated derivatives of the common bases have been found. Another class has the sugar linked to an unusual position of the base. Yet another class has a hydroxyl group of the sugar methylated. Of these minor constituents 18 have been isolated from a single source, namely s-RNA from yeast[1].

The minor constituents arise by direct methylation of the RNA molecule, and the enzymes responsible are referred to as RNA methylases. At least 8 separate RNA methylases have been demonstrated. These enzymes are widely distributed in living organisms[2]. The methylated bases are not distributed at random but are specifically located in the RNA molecule. The biological significance of the methylated bases is not known, but it has been suggested that they constitute part of the recognition mechanism in the transfer of genetic information[2].

Several minor components have also been found in addition to the four common bases of DNA. The DNA of animals and plants contains 5-methylcytosine[3] and that of certain bacteria contains 6-methyladenosine[4]. These constituents arise by direct methylation of DNA. At least two DNA methylases exist. One methylates adenine and the other cytosine of DNA[2].

A summary of these minor nucleosides of the nucleic acids is given in Table 13[5].

References

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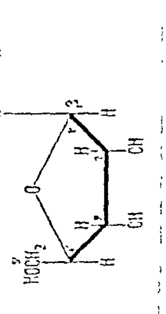
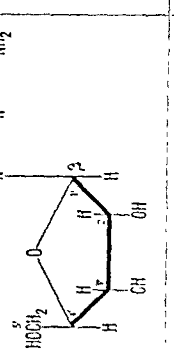
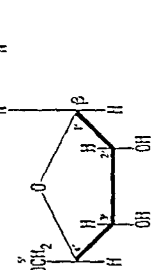
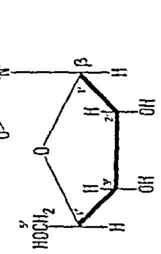
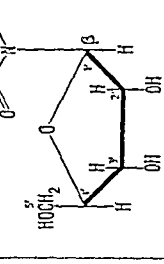
Table 13 Minor (infrequently occurring) nucleosides found in nucleic acids

The minor nucleosides are listed below the formula of the parent compound. Although shown as a parent compound, inosine is itself one of the minor nucleosides.

Adenosine	Guanosine	Inosine	Cytidine	Uridine
				
N^6-Methyladenosine N^6,N^6-Dimethyladenosine 2-Methyladenosine 2'-O-Methyladenosine	1-Methylguanosine 7-Methylguanosine N^2-Methylguanosine N^2,N^2-Dimethylguanosine 2'-O-Methylguanosine N^2-Ribosylguanine	1-Methylinosine	3-Methylcytidine 5-Methylcytidine 2'-O-Methylcytidine	3-Methyluridine 5-Methyluridine* 2'-O-Methyluridine Pseudouridine** 2'-O-Methylpseudouridine**

* This compound is the ribose-containing analogue of thymidine. ** Pseudouridine is 5-ribosyluracil.

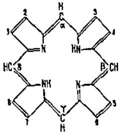
(For references see page 363)

ıyrins[1,2]

hyrins are tetrapyrrolic pigments sometimes found free in but more commonly occurring as divalent metal-ion com-, usually conjugated with proteins. Such proteins often func-i enzymes.

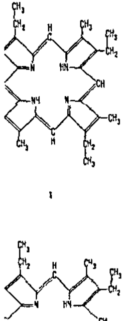
parent compound of the porphyrins is *porphin*, in the mole-which one pyrrole ring and 3 pyrrole-like rings are linked er through their α-carbon atoms by means of methene [–) bridges

Pyrrole

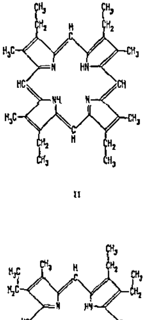


Porphin

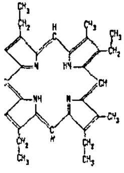
e porphyrin molecule thus forms a closed ring of carbon and gen atoms lying in one plane and containing a central 16-mem-ring of 12 carbon and 4 nitrogen atoms



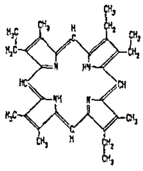
I



II

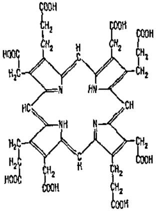


III

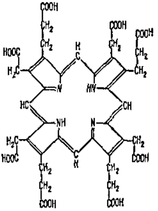


IV

These isomers, known as types I–IV porphyrins, provide the is for the classification of the naturally occurring porphyrins

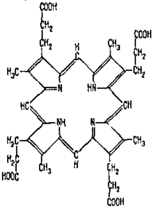


Uroporphyrin I

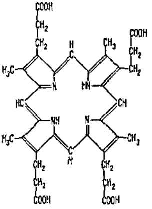


Uroporphyrin III

Decarboxylation of the 4 acetic acid groups gives rise to the *coproporphyrins*, which contain 4 methyl and 4 propionic acid groups

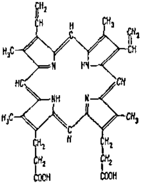


Coproporphyrin I



Coproporphyrin III

Decarboxylation and dehydrogenation of two of the propionic acid groups of coproporphyrin III yield *protoporphyrin IX*, which contains 4 methyl, 2 vinyl and 2 propionic acid groups

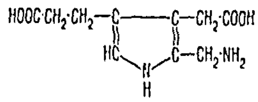
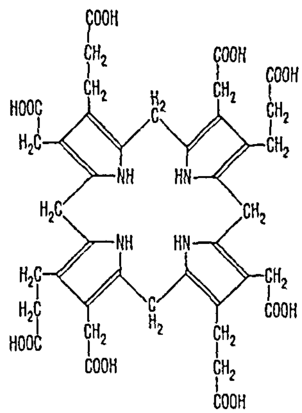
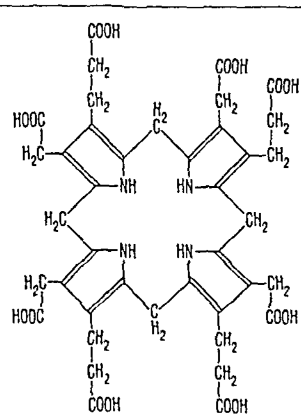
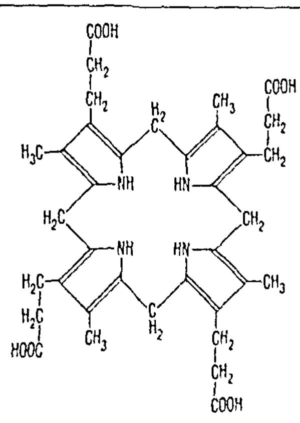


Protoporphyrin IX

pages 360–361)

Data on the naturally occurring porphyrins are summarized in Table 14 on pages 356–359 On the biosynthesis of porphyrins see page 436, on the porphyrias see pages 454–455.

Table 14 Porphyrins of biological importance (and their precursors)

Porphyrin	Structure	Occurrence
Porphobilinogen $C_{10}H_{14}N_2O_4$		Obligatory precursor for the biosynthesis of porphyrins and haem. Present in urine in hepatic porphyria, and in poisoning by lead and monoureide sedatives
Uroporphyrinogen I $C_{40}H_{44}N_4O_{16}$		Metabolite of porphobilinogen
Uroporphyrinogen III $C_{40}H_{44}N_4O_{16}$		Metabolite of porphobilinogen
Coproporphyrinogen I $C_{36}H_{44}N_4O_8$		Metabolite of porphobilinogen

(continued) Porphyrins of biological importance (and their precursors)

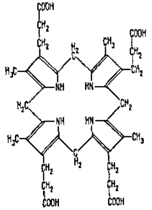
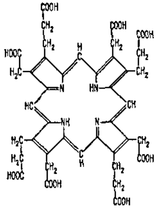
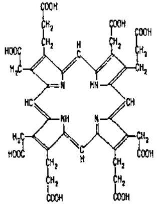
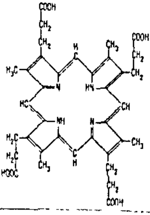
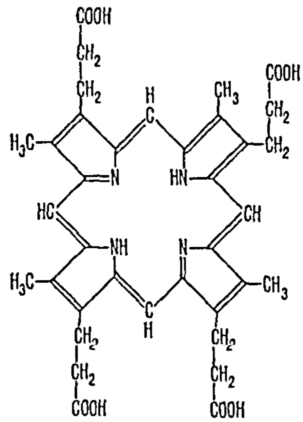
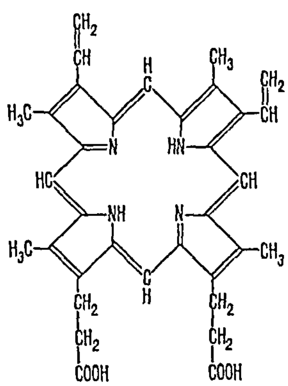
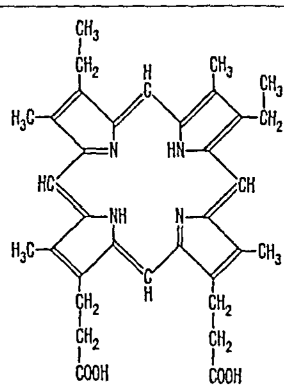
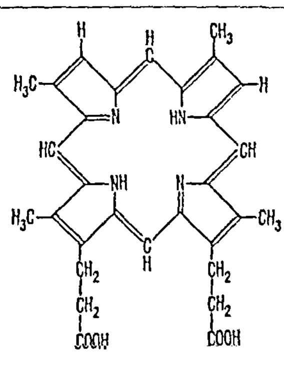
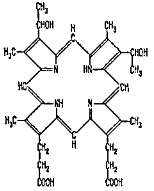
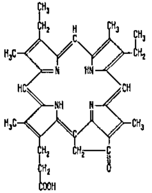
Porphyrin	Structure	Occurrence
porphyrinogen III $H_{44}N_4O_8$		Metabolite of porphobilinogen
porphyrin I $H_{38}N_4O_{16}$		Found in large amounts in erythrocytes and other tissues, especially the teeth and bones of patients with erythropoietic porphyria. Also present in small amounts in urine
oporphyrin III $C_{40}H_{38}N_4O_{16}$		Found in very small amounts in human urine, in larger amounts in some forms of porphyria and lead poisoning
oproporphyrin I $C_{36}H_{38}N_4O_8$		Found in large amounts in erythrocytes and other [illegible]

Table 14 (continued) Porphyrins of biological importance

Porphyrin	Structure	Occurrence
Coproporphyrin III $C_{36}H_{38}N_4O_8$		Found free in faeces, urine, erythrocytes, bile, yeast and bacteria. Increased pathologically in porphyrinuria and porphyria. Also formed in the putrefaction of meat
Protoporphyrin IX $C_{34}H_{34}N_4O_4$		Found in bone marrow, erythrocytes, liver and faeces. The iron complexes form the prosthetic groups of haemoglobin, myoglobin, catalase, peroxidases and cytochrome b. Also formed in the putrefaction of meat
Mesoporphyrin IX $C_{34}H_{38}N_4O_4$		Occurs in normal human faeces, possibly also in human fistula bile
Deuteroporphyrin IX $C_{30}H_{30}N_4O_4$		Occurs in human faeces after ingestion of blood or following haemorrhages of the gastro-intestinal tract. Formed together with protoporphyrin and coproporphyrin in the putrefaction of meat

(For references see page 363)

ded) Porphyrins of biological importance

›hyrin	Structure	Occurrence
rphyrin IX O_6		Probably not of biological importance. Natural occurrence not definitely established, but may be present in natural coproporphyrin and deuteroporphyrin fractions
ırin $_4O_5$		Occurs in large amounts in bile and faeces of ruminants. Causes photosensitization if bile flow is impeded

›menclature of iron porphyrins

Coordination position occupied by		Authors		
(a)	(b)	Lemberg and Legge[1]	Pauling[4], Barron[5]	Anson[6], Keilin[7]
H_2O	H_2O	Heme*	Ferroheme	Haem
OH	*H_2O*	*Hematin***	*Ferriheme hydroxide*	*Haematin*
Cl	-	Hemin	Ferriheme chloride	Haemin
N-Compound	*N*-Compound	Hemochrome	Ferro-hemochromogen	Haemochromogen
N-Compound	*N*-Compound	Hemichrome	Ferri-hemochromogen	Parahaematin
Globin	H_2O	Hemoglobin	Hemoglobin	Haemoglobin
Globin	O_2	Oxyhemoglobin	Oxyhemoglobin	Oxyhaemoglobin
Globin	H_2O	Hemiglobin	Ferrihemoglobin	Acid methaemoglobin
Globin	OH	Hemiglobin hydroxide	Ferrihemoglobin hydroxide	Alkaline methaemoglobin
Globin	CO	Carboxyhemoglobin	Carbon monoxide hemoglobin	-

rred to by some authors as ferroprotoporphyrin ** Also referred to by some authors as ferriprotoporphyrin hydroxide

rrins (haem derivatives)

ıncy of porphyrins to form complexes with divalent

iron atom can be occupied by various molecules or groups (a and b in *Table 15*). The term *haem* itself is used to designate the complex of protoporphyrin IX with ferrous iron (Fe^{++}), where the two co-ordination positions are occupied by

(For references see page 363)

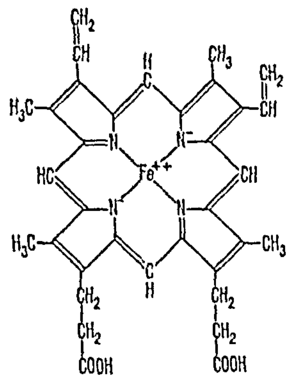
ble 16 Iron porphyrins and haem proteins of biological importance

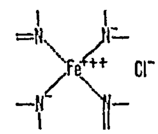
Substance	General nature	Spectral characteristics		Remarks
		Solvent	Absorption maxima in nm	
aem (protohaem) $C_{34}H_{32}N_4O_4Fe$	Ferrous iron complex of protoporphyrin IX. Extremely unstable. Easily oxidized to haematin. See also pages 359 and 362	Phosphate buffer pH7.0	575 550 415	Prosthetic group of haemoglobin. Combines with many nitrogenous bases to form haemochromes
aematin $C_{34}H_{32}N_4O_4Fe$ (OH)	Ferric iron complex of protoporphyrin IX. Moderately stable. See also pages 359 and 362	Acetic acid 10% NaOH Ether	630–635 540 510 400 580 650	Formed from haemoglobin in blood under many different conditions. The pigment of the malarial parasite *Plasmodium* has been shown to consist of haematin[8]
aemoglobin (Hb) (deoxyhaemoglobin)	Compound of globin with 4 molecules of haem. Iron is in the ferrous state and readily oxidized. Globin portion consists of 4 polypeptide chains in the form of 2 pairs of identical chains. The great variety of abnormal haemoglobins is accounted for by differences in the amino-acid sequence and in the way the chains are combined[9] (see also pages 446–448). On the spatial arrangement of the haemoglobin molecule see the literature[18]	Water	560 430	Oxygen carrier in erythrocytes of all vertebrates. One erythrocyte contains ca. 280 million Hb molecules. Combines reversibly with oxygen to form oxyhaemoglobin, and with carbon monoxide to form carboxyhaemoglobin (affinity for carbon monoxide over 100 times that for oxygen)
[yoglobin (myohaemoglobin, deoxymyoglobin)	Unlike haemoglobin, consists of one haem molecule combined with a polypeptide of 153 amino-acid residues[9]. Iron is in the ferrous state. On the spatial arrangement of the myoglobin molecule see the literature[19]	Water	555 435	Found in muscles of higher vertebrates, nematodes and molluscs, where its main function is oxygen storage. Completely saturated with oxygen at low pressures. The affinity of myoglobin for oxygen is greater than that of haemoglobin
xyhaemoglobin	Compound of haemoglobin with 4 molecules of oxygen available physiologically. Iron is in the ferrous state	Water	577 540 412	Present in fresh blood of all vertebrates (see also under 'Haemoglobin' above)
arboxyhaemoglobin	Compound of 4 molecules of carbon monoxide with the 4 iron atoms of haemoglobin	Water	568–572 538 418	Rapidly formed in the body during exposure to carbon monoxide, resulting in failure of oxygen transport by haemoglobin (see also under 'Haemoglobin' above)
[aemiglobin (methaemoglobin)	Similar to haemoglobin except that iron is in the ferric state	Acid solution Alkaline solution	630 500 405 577 540 411	Formed reversibly from haemoglobin by oxidation (ferricyanide, nitrites, chlorates, etc.). Occurs in erythrocytes in larger amounts in some pathological conditions[10]
holeglobin (verdoglobin A, verdohaemoglobin)	Haemoglobin-like compound in which the α-methene bridge is oxidized; formed by coupled oxidation of haemoglobin	Water	670 630	Possibly a normal haemoglobin degradation product and intermediary in bile pigment formation

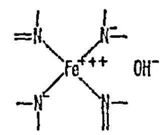
(For references see page 363)

6 (continued) Iron porphyrins and haem proteins of biological importance

Substance	General nature	Spectral characteristics		Remarks
		Solvent	Absorption maxima in nm	
ıaemoglobin rdoglobin S)	Chemical structure not known	Water	620	Formed irreversibly from haemoglobin by action of hydrogen sulphide Present in erythrocytes after ingestion of sulphur, sulphonamides, aromatic amines, occasionally trinitrotoluene, also in septicaemia (especially *Clostridium perfringens* bacteraemia) and severe constipation
:hrome a oup: a, a_3	Prosthetic group is a haem containing a formyl side chain	Water	(Ferro-ferri difference spectrum) Cytochrome a: 605 (α) 444 (γ) Cytochrome a_3: 605 (α) 445 (γ)	Cytochromes a and a_3 are components of the cytochrome c oxidase of the mitochondria of animals, plants and yeast[20]. Ferrocytochrome a_3 combines with cyanide and carbon monoxide, whereas ferrocytochrome a does not The cyanide compound of ferrocytochrome a_3 is autoxidizable. Cytochromes a and a_3 may be part of the same protein ('cytochrome aa'')
chrome c oup: c, c_1	Possess covalent linkages between haem side chains and protein Only thioether linkages are so far known, and the prosthetic groups can be called 'substituted mesohaems'	Water	Ferrocytochrome c: 550 (α) 520 (β) 415 (γ) Ferrocytochrome c_1 553 (α)	Cytochromes c and c_1 are found in the mitochondria of animals, plants and yeast At neutral pH the former is relatively heat-stable, the latter not Cytochrome c has an isoelectric point above pH 7 and the oxidation of its ferro form by oxygen is catalysed by cytochrome oxidase; the oxidation-reduction potential over most of the physiological pH range is ca +0 25 V
›chrome b :oup b, b_5	Prosthetic group is protohaem	Water	Ferrocytochrome b 564 (α) Ferrocytochrome b_5 556 (α)	Cytochrome b occurs in the mitochondria of animals, plants and yeast Cytochrome b_5 is found in animal microsomes It is reduced by NADH in the presence of cytochrome b_5 reductase
ochrome d roup d (a_2)	Prosthetic group is an iron-dihydroporphyrin (phytochlorin) complex	Water	Ferrocytochrome d 645	Found in some bacteria (e g , *E coli*, *Acetobacter peroxidans*) The ferro form is autoxidizable and combines with carbon monoxide
oxidases	Prosthetic group is haematin or a related compound	Weak acids	645 583 548 498 (horse-radish peroxidase)	Occur in plants and animals Biological functions not well known
alase	Prosthetic group is haematin	Water	629 544 506 409 280	Decomposes hydrogen peroxide. Present in respiring cells, highly active in liver, erythrocytes, etc Catalytic activity inhibited by cyanide, hydrogen sulphide, hydroxylamine, azides, aminophenols and 2 4 [illegible]


Haem (protohaem)


Haemin


Haematin

Haem and other ferrous complexes of the porphyrins readily react with bases such as primary amines, pyridine, ammonia, imidazole compounds (e.g., histidine) and hydrazine, the resulting products being known as *haemochromes*.

Haemoproteins are conjugated proteins in which the prosthetic group is haem. They are of two types: 'haemochromes', in which the two free coordination bonds of the haem iron atom are occupied by nitrogen atoms of basic side chains of the protein, and 'open' type haemoproteins, in which at least one of these bonds is not so occupied. Haemoglobin and myoglobin are haemoproteins of the open type, as are catalases and peroxidases, though in the latter the nature of the iron-coordinating groups is not known for certain.

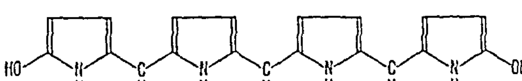
Three types of physiologically active haemoproteins, depending on the valency state of the iron, can be distinguished:

1. Fe remains divalent:	haemoglobin, myoglobin
2. Fe is reversibly oxidized and reduced:	cytochromes
3. Fe remains trivalent:	catalase and peroxidases

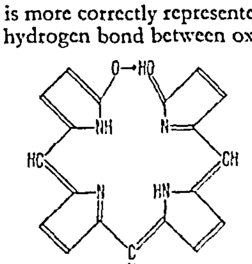
Haemoglobin is the principal representative of a class of haemoproteins whose function is to combine reversibly with oxygen; this reaction does not involve rapid oxidation of the haem iron atom. *Catalases* and *peroxidases* are enzymes responsible for catalysis of electron and/or hydrogen transport, the hydrogen acceptor being either hydrogen peroxide or one of its alkyl derivatives. *Cytochromes* are by definition haemoproteins whose characteristic function is also electron and/or hydrogen transport, but by means of a reversible valency change in their haem iron atom (ferrocytochrome $\rightleftharpoons$ ferricytochrome). For further data on haemoproteins see Table 16, pages 360–361.

Bile pigments[1,11]

The metabolic breakdown of the haemoglobin released by the disintegration of erythrocytes results in the formation of bile pigments. The breakdown occurs by the oxidative cleavage of the porphyrin ring with the loss of a carbon atom to form open-chain tetrapyrroles. Bile pigments are generally represented as linear tetrapyrrolic chains with terminal hydroxyl groups:


(*a*) Linear tetrapyrrolic structure of bile pigments

but their structure is more correctly represented by a tetrapyrrolic 'ring', closed by a hydrogen bond between oxygen atoms:


(*b*) 'Ring' structure of bile pigments

protoporphyrin is released from the globin, with choleglobin as intermediate[12]. The iron released by the catabolism of haemoglobin is largely retained in the body in the form of the protein ferritin, while the bile pigments are excreted. Current views about the formation in the organism of the various bile pigments (see also Table 17, pages 363–364) can be summarized as follows[13]:

Haemoglobin → Choleglobin, Biliverdin

Choleglobin → Bilirubin; Biliverdin → Bilirubin

Bilirubin → Mesobilirubin

Mesobilirubin → *Urobilinogen IX-α* (Mesobilirubinogen)

(+)-Urobilinogen ← *Urobilinogen IX-α* (Mesobilirubinogen) → *Stercobilinogen*

(+)-Urobilinogen → (+)-Urobilin

Urobilinogen IX-α → Urobilin IX-α

Stercobilinogen → Stercobilin

The principal sites of conversion of the haem portion of haemoglobin to bilirubin are believed to be the reticuloendothelial cells of the liver, spleen and bone marrow. In the blood, bilirubin becomes bound to serum albumin (see also pages 576–577) and is rapidly taken up by the liver, whence it reaches the intestine via the bile. The further degradation takes place mainly in the intestine.

VAN DEN BERGH and MÜLLER[14] were the first to observe that there is a difference between serum bilirubin and the bilirubin-like pigments excreted in bile in respect of their coupling with diazotized sulphanilic acid, the latter pigments reacting directly whereas serum bilirubin requires the presence of ethanol (direct and indirect VAN DEN BERGH reactions respectively). Subsequently it was shown[15] that bilirubin undergoes conjugation in the liver cells with glucuronic acid (and possibly other substances) and is excreted into the bile mainly as the diglucuronide and to a smaller extent as the monoglucuronide. This conjugated bilirubin is water-soluble, whereas bilirubin itself is soluble in lipids but insoluble in water. This difference in solubility explains not only the difference in the VAN DEN BERGH reaction but also that in the physiological behaviour of the two types of pigment. Thus it accounts for the fact that bile pigments are excreted in the urine in obstructive jaundice and hepatitis but not in haemolytic jaundice (see below). Since lipids have an affinity for brain tissue, it also explains why a great excess of bilirubin in the blood of infants results in kernicterus.

Jaundice

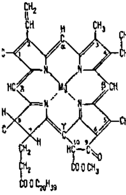
Jaundice may broadly be classified into the haemolytic, obstructive and hepatogenous varieties. In haemolytic jaundice the excessive rate of breakdown of erythrocyte haemoglobin causes bilirubin to pass into the blood stream at a rate greater than that at which it can be conjugated and removed by the liver. Obstructive jaundice occurs when there is obstruction to the outflow of bile from the liver through the biliary ducts. In hepatogenous jaundice destruction of the normal architecture of the liver causes bile pigment to enter the blood stream. In both the latter cases the water-soluble bile pigment is excreted in the urine. See also pages 576–577.

Bilirubinoids

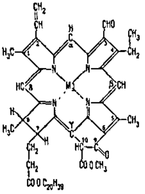
The various intermediates (bilirubinoids) in the conversion of bilirubin to stercobilin by the reductive enzymes of the intestinal bacteria may be partly reabsorbed in the intestinal tract and either returned to the liver or excreted in the urine. Data on the most important of these compounds are summarized in Table 17, pages 363 and 364.

Chlorophylls

Other metallo-phorphyrins occurring in nature include the magnesium porphyrin compounds that are components of the chlorophyll of green plants. The latter has been shown to consist mainly of a mixture of chlorophyll a and chlorophyll b, both of which contain a porphyrin esterified with the long-chain optically active fatty alcohol phytol and magnesium. The porphyrins are charac-



Chlorophyll a



Chlorophyll b

and d In leaf tissue, chlorophylls exist in the form of a protein

Cyanocobalamin (vitamin B_{12})

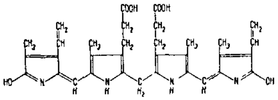
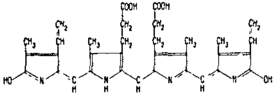
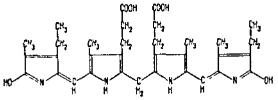
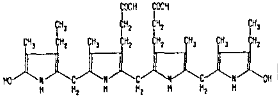
References

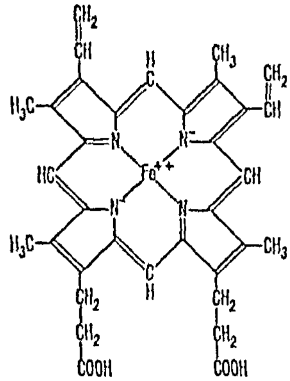
[1] For reviews see LEMBERG and LEGGE, *Hematin Compounds and Bile Pigments*, Interscience, New York, 1949

13 (1948)

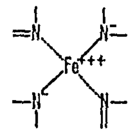
[11] GRAY, C.H., *The Bile Pigments*, Methuen, London, 1953, GRAY, C.H., *Bile Pigments in Health and Disease*, Thomas, Springfield, Ill, 1961, WITH, T K, *Bile Pigments*, Academic Press, New York, 1968, SCHMID, R, in STANBURY et al (Eds), *The Metabolic Basis of Inherited Disease*, 2nd ed, McGRAW-HILL, New York, 1966

Table 17 Bilirubinoids and related compounds

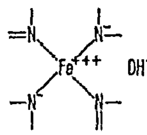
Substance	Structure	Remarks
Bilirubin $C_{33}H_{36}N_4O_6$		Breakdown product of haemoglobin and other haem compounds in reticuloendothelial system Present in excess in serum and tissues in haemolytic jaundice Also found in urine and faeces of infants Conjugated in liver cells with glucuronic acid to form bile pigment
Biliverdin $C_{33}H_{34}N_4O_6$		Breakdown product of haemoglobin, reduced enzymatically in liver to bilirubin Not found
Mesobilirubin $C_{33}H_{40}N_4O_6$		May be present in the small intestine as reduction product of bilirubin
Mesobilane (mesobilirubinogen, urobilinogen IX-α) $C_{33}H_{44}N_4O_6$		Degradation product of bilirubin in liver. Present in normal bile, urine and faeces; increased in pathological conditions



Haem (protohaem)



Haemin



Haematin

Haem and other ferrous complexes of the porphyrins readily react with bases such as primary amines, pyridine, ammonia, imidazole compounds (e.g., histidine) and hydrazine, the resulting products being known as *haemochromes*.

Haemoproteins are conjugated proteins in which the prosthetic group is haem. They are of two types: 'haemochromes', in which the two free coordination bonds of the haem iron atom are occupied by nitrogen atoms of basic side chains of the protein, and 'open' type haemoproteins, in which at least one of these bonds is not so occupied. Haemoglobin and myoglobin are haemoproteins of the open type, as are catalases and peroxidases, though in the latter the nature of the iron-coordinating groups is not known for certain.

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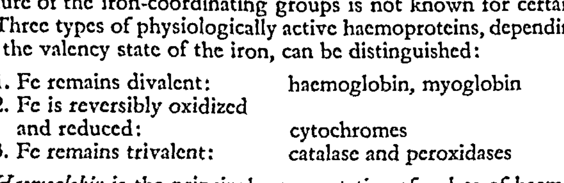
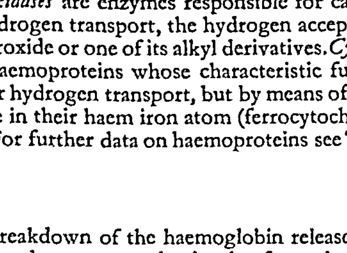


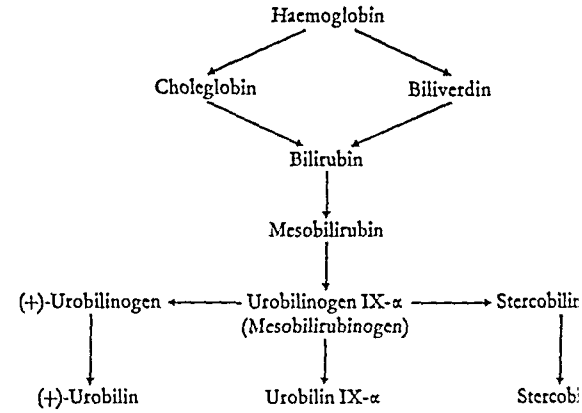
(*a*) Linear tetrapyrrolic structure of bile pigments

but their structure is more correctly represented by a tetrapyrrolic 'ring', closed by a hydrogen bond between oxygen atoms:



(*b*) 'Ring' structure of bile pigments

All naturally occurring bile pigments are derived from protoporphyrin IX by fission at the α-methene link. The possibility exists that the oxidative cleavage of the porphyrin ring occurs before the protoporphyrin is released from the globin, with choleglo intermediate[12]. The iron released by the catabolism of haen bin is largely retained in the body in the form of the protein tin, while the bile pigments are excreted. Current views abo formation in the organism of the various bile pigments (se Table 17, pages 363–364) can be summarized as follows[13]:



The principal sites of conversion of the haem portion of hae globin to bilirubin are believed to be the reticuloendothelial of the liver, spleen and bone marrow. In the blood, bilirubin comes bound to serum albumin (see also pages 576–577) an rapidly taken up by the liver, whence it reaches the intestine via bile. The further degradation takes place mainly in the intest

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Chlorophylls

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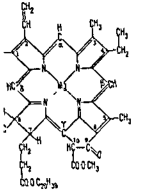
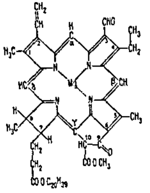
Phytol is also a component of vitamin K_1 (see page 468). Spec tral data have indicated the existence of two further chlorophylls,



Chlorophyll a



Chlorophyll b

and d In leaf tissue, chlorophylls exist in the form of a protein omplex, chloroplastin, which has been isolated[18]

The photosynthetic purple sulphur bacteria contain the pigment acteriochlorophyll This has been shown to differ from chlorophyll a only in the presence of an acetyl group in place of the vinyl group in position 2 and in the hydrogenation of the 3,4 double bond

Cyanocobalamin (vitamin B_{12})

Cyanocobalamin, the cobalt-containing principle of liver ex-

References

[1] For reviews see LEMBERG and LEGGE, *Hematin Compounds and Bile Pigments*

[11] GRAY, C.H., *The Bile Pigments*, Methuen, London, 1953, GRAY, C.H., *Pigments in Health and Disease*, Thomas, Springfield, Ill., 1961; WITH, T. *Bile Pigments*, Academic Press, New York, 1968, SCHMID, R., in STANBURY et al (Eds.), *The Metabolic Basis of Inherited Disease*, 2nd ed., McGRAW-HILL, New York, 1966

Table 17 Bilirubinoids and related compounds

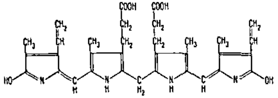
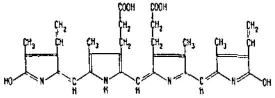
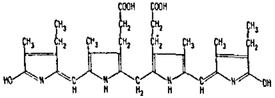
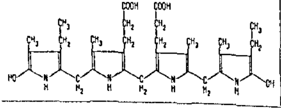
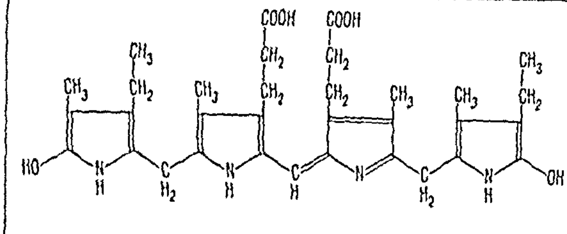
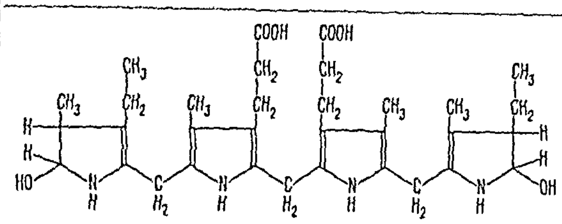
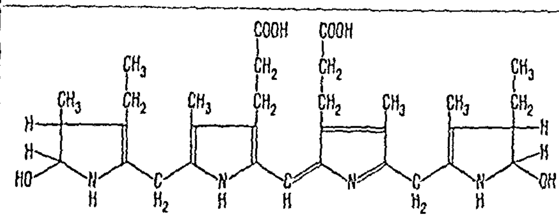
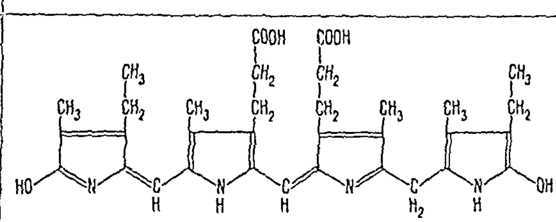
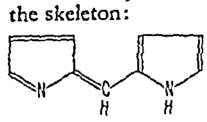
Substance	Structure	Remarks
Bilirubin $C_{33}H_{36}N_4O_6$		Breakdown product of haemoglobin and othe haem compounds in reticuloendothelial system Present in excess in serum and tissues in haemo lytic jaundice. Also found in urine and faeces of infants Conjugated in liver cells with glucuro nic acid to form bile pigment
Biliverdin $C_{33}H_{34}N_4O_6$		Breakdown product of haemoglobin, reduced enzymatically in liver to bilirubin Not found in blood, but present in bile of some animal in placenta of some mammals (uteroverdin) an in egg shells of many birds (oocyan) Als found in meconium of foetus and newborn an in bile after death An iron complex may be th prosthetic group of inactive liver catalase
Mesobilirubin $C_{33}H_{40}N_4O_6$		May be present in the small intestine as redu tion product of bilirubin
Mesobilane (mesobilirubinogen, urobilinogen IX-α) $C_{33}H_{44}N_4O_6$		Degradation product of bilirubin in liver Pre ent in normal bile, urine and faeces, increase in pathological conditions

Table 17 (continued) Bilirubinoids and related compounds

Substance	Structure	Remarks
Mesobilene-(b) (urobilin IX-α) $C_{33}H_{42}N_4O_6$		Oxidation product of mesobilane. in normal urine and faeces
(−)-Tetrahydro-mesobilane (stercobilinogen) $C_{33}H_{44}N_4O_6$		Reduction product of mesobilane excretory product of haemoglobin vertebrates
(−)-Tetrahydro-mesobilene-(b) (stercobilin) $C_{33}H_{46}N_4O_6$		[illegible] faeces and urine
Mesobiliviolin $C_{33}H_{40}N_4O_6$		Found in human faeces, probably d from mesobilane. Forms prosthetic of the phycocyanins (chromoproteins and blue algae) that act as efficient p sensitizers in algal photosynthesis
Mesobilierythrin (mesobilirhodin) $C_{33}H_{40}N_4O_6$	Not established with certainty	Prosthetic group of phycoerythrin o and some blue algae. A sensitizer in photosynthesis
Mesobilifuscins Bilifuscins Propentdyopents $C_{16}H_{18-20}N_2O_{4-5}$	Not definitely established, but known to be dipyrroles containing the skeleton: 	Secondary products of oxidation of pigments and haem compounds, exct in urine and faeces in jaundice and disease; present in gallstones
(+)-Urobilin $C_{33}H_{40}N_4O_6$	Not established with certainty. Strongly dextrorotatory	Isolated from infected bile, where it sumably arises from bilirubin′
(+)-Urobilinogen $C_{33}H_{42}N_4O_6$	Not established with certainty. Strongly dextrorotatory	Isolated from infected bile, where it p sumably arises from bilirubin′

pids

Lipids is the general term for a group of natural products that e soluble in relatively nonpolar solvents, such as mixtures of [illegible]

taglandins (see page 373)

(b) higher straight-chain alcohols, e.g., cetyl (C_{16}), stearyl (C_{18}), ceryl (C_{26}) and myricyl (C_{30}) alcohols
(c) sterols (see page 377), i.e., alcohols containing the cyclopentanoperhydrophenanthrene nucleus, e.g., cholesterol (see page 374), sitosterol, stigmasterol and ergosterol
(d) hydrocarbons, e.g., squalene (see page 374) and the carotenes
(e) the fat-soluble vitamins A, D, E and K (see under 'Vitamins', pages 457–469).

Further reading

Deuel, H. J., *The Lipids*, vol. I, Interscience, New York, 1951; Hilditch, T. P., *The Chemical Constitution of Natural Fats* [illegible]
1964, Lov[illegible]
Methuen, [illegible]
Oxford, 19[illegible]
1960

Table 18 Classification and structural components of saponifiable lipids

Classification of lipids*		Structural components (other than fatty acids)**		
		Ester or amide of	Nitrogenous base	Other
Acylglycerols (fats)	(i) Monoglycerides (ii) Diglycerides (iii) Triglycerides (neutral fats)	Glycerol	–	–
Alkoxydiglycerides		Glycerol	–	Higher aliphatic alcohol
Glycoglycerides		Glycerol	–	Galactose
Glycerophosphatides	(i) Phosphatidic acids	Glycerol	–	Phosphoric acid
	(ii) Phosphatidyl esters: Phosphatidylcholines	Glycerol	Choline	Phosphoric acid
	Phosphatidylethanolamines	Glycerol	Ethanolamine	Phosphoric acid
	Phosphatidylserines	Glycerol	Serine	Phosphoric acid
	(iii) Lysophosphatides	Glycerol	Choline Ethanolamine Serine	Phosphoric acid
	(iv) Inositol phosphatides: Mono-, Di-, Tri-	Glycerol	–	Phosphoric acid, inositol
	(v) Acetal phosphatides	Glycerol	(As for lysophosphatides)	Phosphoric acid, α,β-unsaturated higher aliphatic alcohol
	(vi) Alkyl lysophosphatide ethers	Glycerol	(As for lysophosphatides)	Phosphoric acid, saturated higher aliphatic alcohol
Sphingolipids	(i) Sphingomyelins	Sphingosine and dihydrosphingosine	Choline	Phosphoric acid
	(ii) Cerebrosides	Sphingosine and dihydrosphingosine	–	Hexose or di- or tri-saccharide
	(iii) Sulphatides	Sphingosine and dihydrosphingosine	–	Galactose, sulphuric acid
	(iv) Aminoglycolipids	Sphingosine and dihydrosphingosine	N-Acetylgalactosamine	Glucose, galactose
	(v) Gangliosides	Sphingosine and dihydrosphingosine	N-Acetylgalactosamine	Glucose, galactose, neuraminic acid
Waxes	(i) True waxes	Long-chain aliphatic alcohols	–	–
	(ii) Steryl esters, vitamin A and D_3 esters	Complex cyclic alcohols	–	–

* [illegible] *Chem. Rev.* 2, 243 (1925) [illegible]

Table 19 (continued) Fatty acids

Name	Formula and mol.wt.	Structure	Physical properties	Remarks
Lacceroic acid (dotriacontanoic acid)	$C_{32}H_{64}O_2$ 480.87	$CH_3\cdot(CH_2)_{30}\cdot COOH$	m.p. 96.2°C	Occurs in stick-lac wax (from *Tachardia lacca*) and other natural waxes
		Unsaturated (mono-olefinic) straight-chain monocarboxylic acids		
Acrylic acid (propenoic acid)	$C_3H_4O_2$ 72.06	$CH_2{=}CH\cdot COOH$	m.p. 13°C b.p. 141°C d^{16} 1.062 n_D^{20} 1.4224	
trans-(α-)Crotonic acid (*trans*-butenoic acid)	$C_4H_6O_2$ 86.09	$CH_3\cdot CH$ ‖ $HC\cdot COOH$	m.p. 72°C b.p. 189°C d^{72} 0.973 $n_D^{79.7}$ 1.4228	Constituent of croton oil (from *Croton tiglium* seeds)
Iso-(β-)crotonic acid (*cis*-butenoic acid)	$C_4H_6O_2$ 86.09	$HC\cdot CH_3$ ‖ $HC\cdot COOH$	m.p. 15.5°C b.p. 169°C d^{15} 1.0312 n_D^{20} 1.4457	Readily isomerizes to the *trans*-acid
Δ²-Hexenoic acid	$C_6H_{10}O_2$ 114.15	$CH_3\cdot(CH_2)_2\cdot CH{=}CH\cdot COOH$	m.p. 32°C b.p. 217°C d^{40} 0.9627 n_D^{40} 1.4601	Occurs in Japanese peppermint oil
Δ⁴-Decenoic acid (obtusilic acid)	$C_{10}H_{18}O_2$ 170.25	$CH_3\cdot(CH_2)_4\cdot CH{=}CH\,(CH_2)_2\cdot COOH$	b.p. 148–150°C/13 d^{20} 0.9197 n_D^{20} 1.4497	Occurs in seed fat of *Lindera obtusiloba*
Δ⁹-Decenoic acid	$C_{10}H_{18}O_2$ 170.25	$CH_2{=}CH\cdot(CH_2)_7\cdot COOH$	b.p. 143–148°C/15 d^{15} 0.9238 n_D^{20} 1.4488	Occurs in butter and milk fats and in sperm head oil
Δ⁴-Dodecenoic acid (linderic acid)	$C_{12}H_{22}O_2$ 198.31	$CH_3\cdot(CH_2)_6\cdot CH{=}CH\,(CH_2)_2\cdot COOH$	m.p. 1–1.3°C b.p. 170–172°C/13 d^{20} 0.9081 n_D^{20} 1.4529	Occurs in various seed oils, e.g., *Lindera obtusiloba*
Δ⁵-Dodecenoic acid (lauroleic acid)	$C_{12}H_{22}O_2$ 198.31	$CH_3\cdot(CH_2)_5\cdot CH{=}CH\cdot(CH_2)_3\cdot COOH$	d^{15} 0.9130 n_D^{15} 1.4535	Occurs in sperm blubber and head oil
Δ⁹-Dodecenoic acid	$C_{12}H_{22}O_2$ 198.31	$CH_3\cdot CH_2\cdot CH{=}CH\cdot(CH_2)_7\cdot COOH$	–	Occurs in fat of cow's milk
Δ⁴-Tetradecenoic acid (tsuzuic acid)	$C_{14}H_{26}O_2$ 226.36	$CH_3\cdot(CH_2)_8\,CH{=}CH\cdot(CH_2)_2\cdot COOH$	m.p. 18–18.5°C b.p. 185–188°C/13 d^{20} 0.9024 n_D^{20} 1.4557	Occurs in various tropical plant oils, esp. tsuzu oil
Δ⁵-Tetradecenoic acid (physeteric acid)	$C_{14}H_{26}O_2$ 226.36	$CH_3\cdot(CH_2)_7\cdot CH{=}CH\cdot(CH_2)_3\cdot COOH$	d^{20} 0.9046 n_D^{20} 1.4552	Occurs in whale blubber and sardine oil
Δ⁹-Tetradecenoic acid (myristoleic acid)	$C_{14}H_{26}O_2$ 226.36	$CH_3\cdot(CH_2)_3\cdot CH{=}CH\,(CH_2)_7\cdot COOH$	d^{20} 0.9018 n_D^{20} 1.4549	Occurs in milk fat and depot and liver fat of many animals
Δ⁹-Hexadecenoic acid (palmitoleic acid)	$C_{16}H_{30}O_2$ 254.42	$CH_3\cdot(CH_2)_5\cdot CH{=}CH\,(CH_2)_7\,COOH$	m.p. 1°C b.p. 218–220°C d^{15} 0.9003	Widely distributed. In marine oils (15–20% of total fatty acids), in depot and milk fat of animals, vegetable oils and fats

Fatty acids

	Formula and mol wt	Structure	Physical properties	Remarks (for references see page 372)
ic id)	$C_{18}H_{34}O_2$ 282 47	$CH_3(CH_2)_{10}CH{=}CH(CH_2)_4COOH$	m p 32–33°C b p 208–210°C/10 d^{40} 0 882 4 n_D^{47} 1 453 5	Occurs in seeds of aromatic plants (parsley, celery, etc.) and in some umbellate fats
	$C_{18}H_{34}O_2$ 282 47	$CH(CH_2)_7COOH$ $\Vert$ $CH(CH_2)_7CH_3$	m p. 13°C b p 286°C/100 d^{18} 0 895 n_D^{18} 1.458 23	Most abundant of the unsaturated fatty acids Present in nearly all natural fats (one-third of fatty acids of cow's milk, phosphatides) Occurs in traces in human urine
	$C_{18}H_{34}O_2$ 282 47	$CH_3(CH_2)_7CH$ $\Vert$ $CH(CH_2)_7COOH$	m p 44–45°C b p. 288°C/100 d^{79} 0 851 n_D^{80} 1 440 5	Formed by isomerization of oleic acid
id	$C_{18}H_{34}O_2$ 282 47	$CH_3(CH_2)_5CH$ $\Vert$ $CH(CH_2)_9COOH$	m p 42 5°C d^{70} 0 856 0 n_D^{60} 1 443 9	Occurs in many animal fats and vegetable oils
	$C_{18}H_{34}O_2$ 282 47	$CH(CH_2)_9COOH$ $\Vert$ $CH(CH_2)_5CH_3$	m p 12 4–13°C	Has been shown to be the haemolytic acid occurring in plasma and various animal tissues[1] Also present in *Lactobacillus* species[2]
c	$C_{18}H_{34}O_2$ 282.47	$CH_3(CH_2)_4CH{=}CH(CH_2)_{10}COOH$	–	Occurs in partially hydrogenated peanut oil
	$C_{20}H_{38}O_2$ 310 52	$CH_3(CH_2)_9CH{=}CH(CH_2)_7COOH$	m p. 24 5°C	*Cis* and *trans* forms In many fish and marine animal oils, in vegetable oils, in brain phosphatides
cid	$C_{20}H_{38}O_2$ 310 52	$CH_3(CH_2)_7CH{=}CH(CH_2)_9COOH$	m p *cis* 22°C *trans* 52–53°C	Principal acid of jojoba nuts ('goat nuts'), also in seed oil of *Conringia orientalis*, rape- and mustard seed oils, fish oils
nic	$C_{22}H_{42}O_2$ 338 58	$CH_3(CH_2)_9CH{=}CH(CH_2)_9COOH$	m p 32–33°C	Occurs in various marine oils
id)	$C_{22}H_{42}O_2$ 338 58	$CH(CH_2)_{11}COOH$ $\Vert$ $CH(CH_2)_7CH_3$	m p 33 5°C b p 281°C/30 d^{55} 0 860 n_D^{45} 1 448 0	Occurs in seed oils, esp. rapeseed oil
id)	$C_{22}H_{42}O_2$ 338 58	$CH_3(CH_2)_7CH$ $\Vert$ $CH(CH_2)_{11}COOH$	m p 61 5°C b p 282°C/30 d^{57} 0 858 5 n_D^{100} 1 434 7	Formed by isomerization of erucic acid
.	$C_{24}H_{46}O_2$ 366 63	$CH(CH_2)_{13}COOH$ $\Vert$ $CH(CH_2)_7CH_3$	m p. 40 5–41°C n_D^{45} 1 453 5	Occurs in shark and ray liver oils, in brain cerebrosides (nervone) and sphingomyelins[3]
.	$C_{26}H_{50}O_2$ 394 69	$CH_3(CH_2)_7CH{=}CH(CH_2)_{15}COOH$	m p 45°C	Occurs in *Ximenia americana* (tallow-wood) A hexacosenoic acid is found with nervonic acid in brain cerebrosides

Table 19 (continued) Fatty acids

Name	Formula and mol.wt.	Structure	Physical properties	Remarks
		Unsaturated (polyolefinic) straight-chain monocarboxylic acids		
Sorbic acid ($\Delta^{2,4}$-hexadienoic acid)	$C_6H_8O_2$ 112.13	$CH_3{\cdot}CH{=}CH\,CH{=}CH\,COOH$	m.p. 134.5°C b.p. 228°C (decomp.)	Occurs as lactone in oil of unripe mou berries
Linoleic acid (*cis-cis*-$\Delta^{9,12}$-octadecadienoic acid)	$C_{18}H_{32}O_2$ 280.45	$CH_3{\cdot}(CH_2)_4{\cdot}CH$ ‖ $CH\,CH_2{\cdot}CH$ ‖ $CH{\cdot}(CH_2)_7{\cdot}COOH$	m.p. −11 (−5)°C b.p. 230°C/16 d^{20} 0.9025 n_D^{20} 1.4699	Widely distributed in plants, esp. in hemp and cottonseed oils. Also in lipi mals (component of phosphatides, etc. tial dietary component
Hiragonic acid ($\Delta^{6,10,14}$-hexadecatrienoic acid)	$C_{16}H_{26}O_2$ 250.38	$CH\,(CH_2)_2{\cdot}CH{=}CH\,CH_3$ ‖ $CH\,(CH_2)_2{\cdot}CH{=}CH{\cdot}(CH_2)_4{\cdot}COOH$	d^{20} 0.9288 n_D^{20} 1.4855	Occurs in sardine oil
α-Eleostearic acid (*cis*-$\Delta^{9,11,13}$-octadecatrienoic acid)	$C_{18}H_{30}O_2$ 278.44	$CH_3{\cdot}(CH_2)_3{\cdot}(CH{=}CH)_3{\cdot}(CH_2)_7{\cdot}COOH$	m.p. 48°C b.p. 235°C/12 d^{46} 0.8980 n_D^{50} 1.5080	Occurs in vegetable oils, esp. tung oil
β-Eleostearic acid (*trans*-$\Delta^{9,11,13}$-octadecatrienoic acid)	$C_{18}H_{30}O_2$ 278.44		m.p. 71°C d^{80} 0.8839 n_D^{74} 1.5000	Formed from α-eleostearic acid by ac light, heat and chemical reagents
Linolenic acid ($\Delta^{9,12,15}$-octadecatrienoic acid)	$C_{18}H_{30}O_2$ 278.44	$CH{\cdot}CH_2{\cdot}CH{=}CH\,CH_2{\cdot}CH_3$ ‖ $CH\,CH_2{\cdot}CH{=}CH{\cdot}(CH_2)_7{\cdot}COOH$	m.p. −11.2 to −11°C b.p. 230–232°C/17 d^{20} 0.9046 n_D^{20} 1.4780	Occurs in many vegetable oils, esp. dry such as linseed oil. Also in traces in ani (phosphatides)
Stearidonic acid (moroctic acid, $\Delta^{4,8,12,15}$-octadecatetraenoic acid)	$C_{18}H_{28}O_2$ 276.42	$CH_3{\cdot}CH_2{\cdot}CH{=}CH\,CH_2\,CH$ ‖ $CH\,(CH_2)_2\,CH{=}CH{\cdot}(CH_2)_2{\cdot}CH$ ‖ $CH\,(CH_2)_2{\cdot}COOH$	d^{20} 0.9297 n_D^{20} 1.4911	Occurs in fish oils. The position of the bonds is not confirmed
Timnodonic acid ($\Delta^{4,8,12,15,18}$-eicosapentaenoic acid)	$C_{20}H_{30}O_2$ 302.46	$CH_3{\cdot}CH{=}CH\,CH_2{\cdot}CH{=}CH$ | $CH{\cdot}(CH_2)_2{\cdot}CH{=}CH{\cdot}CH_2$ ‖ $CH{\cdot}(CH_2)_2{\cdot}CH{=}CH\,(CH_2)_2{\cdot}COOH$	–	Occurs in sardine oil, cod-liver oil, pilot oil and oil from *Squalus sucklei* (spiny do
Arachidonic acid ($\Delta^{5,8,11,14}$-eicosatetraenoic acid)	$C_{20}H_{32}O_2$ 304.48	$CH_3{\cdot}(CH_2)_4{\cdot}CH{=}CH\,CH_2{\cdot}CH$ ‖ $CH\,CH_2\,CH{=}CH\,CH_2{\cdot}CH$ ‖ $CH{\cdot}(CH_2)_3{\cdot}COOH$	m.p. −49.5°C n_D^{20} 1.8482	Occurs in 'Essential' etary linoleic acid
Clupanodonic acid ($\Delta^{4,8,12,15,19}$-docosapentaenoic acid)	$C_{22}H_{34}O_2$ 330.52	$CH_3{\cdot}CH_2{\cdot}CH{=}CH\,(CH_2)_2{\cdot}CH$ ‖ $CH\,(CH_2)_2{\cdot}CH{=}CH\,CH_2{\cdot}CH$ ‖ $CH\,(CH_2)_2{\cdot}CH{=}CH{\cdot}(CH_2)_2{\cdot}COOH$	m.p. < −78°C b.p. 236°C/5 d^{20} 0.9290 n_D^{20} 1.4868	Occurs in fish oils
Nisinic acid ($\Delta^{4,8,12,15,18,21}$-tetracosahexaenoic acid)	$C_{24}H_{36}O_2$ 356.55	$CH_3{\cdot}CH_2{\cdot}CH{=}CH\,CH_2{\cdot}CH{=}CH\,CH_2$ | $CH\,(CH_2)_2{\cdot}CH{=}CH\,CH_2{\cdot}CH{=}CH$ ‖ $CH\,(CH_2)_2{\cdot}CH{=}CH\,(CH_2)_2{\cdot}COOH$	–	Occurs in tunny oil
Thynnic acid (Δ?-hexacosahexaenoic acid)	$C_{26}H_{40}O_2$ 384.61	–	d^{20} 0.9433 n_D^{20} 1.5022	Occurs in tunny oil

le 19 (continued) Fatty acids

Name	Formula and mol wt	Structure	Physical properties	Remarks (for references see page 372)
		Unsaturated (acetylenic) straight-chain monocarboxylic acids		
ıriric acid (6-stearolic acid, 6-octadecynoic acid)	$C_{18}H_{32}O_2$ 280 45	$CH_3(CH_2)_{10}C{\equiv}C(CH_2)_4COOH$	m p 50 5°C	Occurs in fat of *Picramnia* spp. (tariri) (bitter-bush oil)
earolic acid (9-octadecynoic acid)	$C_{18}H_{32}O_2$ 280.45	$CH_3(CH_2)_7C{\equiv}C(CH_2)_7COOH$	m p 48 5°C b p. 260°C	Formed by oxidation of oleic or elaidic acid
henolic acid (13-docosynoic acid)	$C_{22}H_{40}O_2$ 336 56	$CH_3(CH_2)_7C{\equiv}C(CH_2)_{11}COOH$	m p. 57 5°C	Formed by oxidation of erucic or brassidic acid
		Branched-chain monocarboxylic acids		
Isobutyric acid (2-methyl-propanoic acid)	$C_4H_8O_2$ 88 11	$(CH_3)_2CH\,COOH$	m p. −47°C b p 154 4°C d^{20} 0 949 n_D^{20} 1 393	Occurs free in carob beans (*Ceratonia siliqua*), as ethyl ester in croton oil, also in faeces and as product of enzymic breakdown of proteins Intermediate in metabolism of valine (see page 396)
Isovaleric acid (3-methylbutanoic acid)	$C_5H_{10}O_2$ 102 13	$(CH_3)_2CH\,CH_2\,COOH$	m p −51°C b p 176 7°C d^{15} 0 937 $n_D^{22.4}$ 1 501 78	[illegible]
Tiglic acid (cis-2 methyl-Δ^2-butenoic acid)	$C_5H_8O_2$ 100 12	$CH_3CH{=}\underset{CH_3}{\underset{\vert}{C}}\,COOH$	m p 64 5°C b p 198 5°C d^{76} 0 964 n_D^{77} 1 434 2	Occurs in croton oil (glyceride); in Roman cumin oil (esters), in geranium oils Intermediate in metabolism of isoleucine (see page 396)
Isomyristic acid (13-methyltridecanoic acid)	$C_{14}H_{28}O_2$ 228 38	$CH_3\underset{CH_3}{\underset{\vert}{CH}}(CH_2)_{10}COOH$	m p 51°C	Occurs together with other even-numbered *iso* acids from $C_{10\,br}$ to $C_{28\,br}$ as esters in wool wax[4]
*ante*Isomargaric acid (14-methylhexadecanoic acid)	$C_{17}H_{34}O_2$ 270 46	$CH_3CH_2\underset{CH_3}{\underset{\vert}{CH}}(CH_2)_{12}COOH$	m p. 36 8°C $[\alpha]_D$ +5 2°	Occurs together with other odd-numbered *anteiso* acids from $C_{9\,br}$ to $C_{31\,br}$ as esters in wool wax[4]
Tuberculostearic acid (D-[−] 10-methyl-octadecanoic acid)	$C_{19}H_{38}O_2$ 298 51	$CH_3(CH_2)_7\underset{CH_3}{\underset{\vert}{CH}}(CH_2)_8COOH$	m p 12 5–12 9 (23 5–25 8)°C b p 180°C/0 1 d^{24} 0 877 1 n_D^{25} 1 451 2 $[\alpha]_D^{25}$ −0 08°	Occurs free in lipids of tubercle bacilli and *Mycobacterium leprae*[5]
Phytanic acid (3,7,11,15-tetramethylhexadecanoic acid)	$C_{20}H_{40}O_2$ 312 54	$CH_3\underset{CH_3}{\underset{\vert}{CH}}(CH_2)_3\underset{CH_3}{\underset{\vert}{CH}}(CH_2)_3\underset{CH_3}{\underset{\vert}{CH}}(CH_2)_3\underset{CH_3}{\underset{\vert}{CH}}CH_2COOH$	m p −6 to −7°C	Present in traces in animal fats, butter and in blood serum (increased in REFSUM's syndrome)[6]

Table 19 (concluded) Fatty acids

Name	Formula and mol.wt.	Structure	Physical properties	Remarks
Mycolipenic acid ([+]-2,4,6-tri-methyltetracos-2-enoic acid)	$C_{27}H_{52}O_2$ 408.71	$CH_3\cdot(CH_2)_{17}\cdot\underset{CH_3}{CH}\cdot CH_2\cdot\underset{CH_3}{CH}\cdot CH{=}\underset{CH_3}{C}\,COOH$	–	One of the 3 phthioic acids of tuber
Mycoceranic acid	$C_{32}H_{64}O_2$ 480.87	$CH_3\cdot(CH_2)_{22}\cdot\underset{CH_3}{CH}\cdot CH_2\cdot\underset{CH_3}{CH}\cdot CH_2\cdot\underset{CH_3}{CH}\cdot COOH$	–	In the lipids of tubercle bacilli[7]
		Hydroxy acids		
α-Hydroxymyristic acid (2-hydroxytetra-decanoic acid)	$C_{14}H_{28}O_3$ 244.38	$CH_3\cdot(CH_2)_{11}\cdot CH(OH)\cdot COOH$	m.p. 81–82°C	Occurs as esters in wool wax[4]
α-Hydroxypalmitic acid (2-hydroxyhexa-decanoic acid)	$C_{16}H_{32}O_3$ 272.43	$CH_3\cdot(CH_2)_{13}CH(OH)\cdot COOH$	m.p. 86°C $[\alpha]_D$ −1.0°	Occurs as esters in wool wax[4]
α-Hydroxystearic acid (2-hydroxyocta-decanoic acid)	$C_{18}H_{36}O_3$ 300.49	$CH_3\cdot(CH_2)_{15}CH(OH)\cdot COOH$	m.p. 93°C	Minor component of cerebrosides human brain
Ricinoleic acid (*cis*-12-hydroxy-Δ^9-octadecenoic acid)	$C_{18}H_{34}O_3$ 298.47	$CH\,CH_2\,CH(OH)\,(CH_2)_5\cdot CH_3$ ‖ $CH\cdot(CH_2)_7\,COOH$	m.p. 5, 7.7 and 16°C (3 forms) b.p. 250°C/15 n_D^{20} 1.4711 $[\alpha]_D^{20}$ +7.8°	As glyceride, chief constituent of cas
2-Hydroxytrico-sanoic acid	$C_{23}H_{46}O_3$ 370.62	$CH_3\cdot(CH_2)_{20}CH(OH)\cdot COOH$	–	Component of normal brain cerebros tent of about 7% of total fatty acids
Cerebronic acid (phrenosinic acid, 2-hydroxytetra-cosanoic acid)	$C_{24}H_{48}O_3$ 384.65	$CH_3\,(CH_2)_{21}\cdot CH(OH)\,COOH$	m.p. 90–93 (102)°C $[\alpha]_D^{22}$ +3.33°	Component of cerebroside phreno bron). About 15% of total fatty acid cerebrosides[8]
2-Hydroxynervonic acid (2-hydroxy-Δ^{15}-tetracosenoic acid)	$C_{24}H_{46}O_3$ 382.63	$CH_3\cdot(CH_2)_7\cdot CH{=}CH\cdot(CH_2)_{12}\cdot CH(OH)\cdot COOH$	m.p. 65°C $[\alpha]_D^{20}$ +2.87°	Component of cerebroside hydroxyn which the isomeric Δ^{17}-acid is also a co About 12% of total fatty acids of b brosides

References

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(For references see page 377)

s'

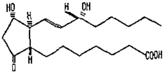
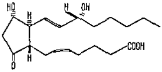
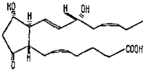
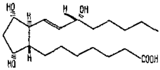
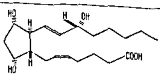
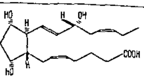
ıds are aliphatic monocarboxylic acids, R COOH, where rated or unsaturated, straight-chain or branched radical.

. trace amounts, e g , elaidic acid (*trans* isomer of oleic l vaccenic acid (*trans*-11-octadecenoic acid) *Cis-trans* geo- isomerism is illustrated by the case of oleic and elaidic

$CH(CH_2)_7COOH$ ‖ $CH(CH_2)_7CH_3$	$CH(CH_2)_7COOH$ ‖ $CH_3(CH_2)_7CH$
Oleic acid (*cis*)	Elaidic acid (*trans*)

Unsaturated fatty acids with more than one double bond (polyolefinic or polyethenoid acids) play an important role in animal nutrition, some are apparently not synthesized in the organism at a rate sufficient to meet the requirements of growth and are therefore essential constituents of the diet The most important of these are *cis-cis*-linoleic and arachidonic acids, the so-called 'essential fatty acids', the ingestion of any of which is effective in preventing or curing the fat-deficiency syndrome due to a completely fat free diet (see page 492)

Prostaglandins

Trivial name	Formula and mol wt	Chemical name	Structure
glandin E_1	$C_{20}H_{34}O_5$ 354.49	11α,15-Dihydroxy-9-ketoprost-13-enoic acid	
ıglandin E_2	$C_{20}H_{32}O_5$ 352.48	11α,15-Dihydroxy-9-ketoprosta-5,13-dienoic acid	
aglandin E_3	$C_{20}H_{30}O_5$ 350.46	11α,15-Dihydroxy-9-ketoprosta-5,13,17-trienoic acid	
aglandin $F_{1\alpha}$	$C_{20}H_{36}O_5$ 355.50	9α,11α,15-Trihydroxyprost-13-enoic acid	
taglandin $F_{2\alpha}$	$C_{20}H_{34}O_5$ 353.48	9α,11α,15-Trihydroxyprosta-5,13-dienoic acid	
staglandin $F_{3\alpha}$	$C_{20}H_{32}O_5$ 351.47	9α,11α,15-Trihydroxyprosta-5,13,17-trienoic acid	

Constituents of Living Matter – Lipids

(For references see page 377)

Acylglycerols (fats)

The acylglycerols are formed by esterification of glycerol with one, two or three fatty-acid residues, yielding respectively a mono-, di- or triglyceride.

The natural fats are composed almost exclusively of triglycerides (neutral fats) together with traces of mono- and diglycerides. Lipids of the two latter types are formed during digestion and absorption of triglycerides and are found among the circulating lipids of the plasma.

At room temperature natural fats may be solid or liquid, and most contain at least 5 and up to 12 or more different fatty-acid residues. Chemically, they are complex mixtures of mixed triglycerides.

$CH_2\cdot O\,CO\,R$	$CH_2\cdot OH$	$CH_2\cdot O\,CO\,R$	$CH_2\cdot O\,CO\,R$	$CH_2\cdot O\,CO\cdot R$
$CH\,OH$	$CH\,O\,CO\,R$	$CH\cdot O\,CO\cdot R'$	$CH\cdot OH$	$CH\cdot O\cdot CO\,R'$
$CH_2\cdot OH$	$CH_2\cdot OH$	$CH_2\cdot OH$	$CH_2\cdot O\cdot CO\cdot R'$	$CH_2\cdot O\cdot CO\cdot R''$
α-Mono-glyceride (1-acyl-glycerol)	β-Mono-glyceride (2-acyl-glycerol)	α,β-Di-glyceride (1,2-diacyl-glycerol)	α,α'-Di-glyceride (1,3-diacyl-glycerol)	Triglyceride (1,2,3-tri-acylglycerol)

The tendency in all natural fats is towards maximum heterogeneity in the composition of the constituent triglycerides.

The fatty acids of most natural fats consist of mixtures of saturated and unsaturated acids. In general, the higher the proportion of saturated to unsaturated acids, the higher the melting point of the fat.

From the standpoint of their fatty-acid composition, the depot fats of land mammals are characterized by a preponderance of oleic acid, palmitic acid and in some important cases (e.g., ox, sheep) stearic acid. In the milk fat of land mammals this preponderance is diminished to an extent corresponding to the additional presence of the lower saturated fatty acids C_{12} down to C_4 (butyric acid). The depot fat of man contains the following percentages (by weight) of fatty acids: oleic 45, palmitic 25, linoleic 8, palmitoleic 7, stearic 6. The fats of aquatic animals contain mainly the higher unsaturated acids C_{16} to C_{22} together with usually 10–18% of palmitic acid.

Vegetable oils are often rich in the unsaturated C_{18} acids oleic ($C_{18:1}$), linoleic ($C_{18:2}$) and linolenic ($C_{18:3}$). The seed fats of the *Palmae* are rich in lower saturated fatty acids (e.g., 37–51% C_{12}, some C_{10} and C_8 in coconut oil), and the *Myristicaceae* yield much myristic acid (60–77% C_{14} in nutmeg oil).

In any particular tissue in the same species of animal the composition of the fat shows variations, and it is known that this is due at least in part to dietary differences. An example is the 'soft pork' produced from swine fed on soybean oil.

Absorption, transport and storage of fats[5]

The dietary triglycerides, which contain long-chain or medium-chain fatty acids, are hydrolysed in the intestine by pancreatic lipase in the presence of conjugated bile salts to yield β-monoglycerides and free fatty acids. The β-monoglycerides may in small part be isomerized to their α-isomers. The reaction products, in the form of bile-salt micelles, are mainly absorbed in the upper gut. Both α- and β-monoglycerides are readily absorbed by the intestinal mucosa. A small part is hydrolysed and some is converted into phospholipids. The major portion, however, is directly acylated to triglycerides by enzymes present in the brush border or in the microsomes. This resynthesis of triglycerides is not a random process and certain fatty acids are preferred in given positions of the glycerol molecule. Medium-chain fatty acids are not re-esterified by the intestinal mucosa but transported via the portal circulation to the liver, where they are largely oxidized. Most of the reformed triglycerides pass from the villi via the lacteals, the intestinal lymphatics, the thoracic duct and the subclavian vein into the systemic blood stream, but a small portion may reach the liver via the portal circulation.

Blood fats. Fats are transported in the body by the blood stream in the form of fine droplets of 1 µm or less in diameter known as *chylomicrons*. They are surrounded by a stabilizing film of protein (α- and β-globulins) and can be separated by centrifuging. The level of fats (and of other lipids) in the blood (see pages 590 sq.) rises after digestion of a meal containing fat. Hyperlipaemia also occurs after several days' fasting, when it is due to increased metabolism of depot fat following the exhaustion of glycogen reserves. Ingestion of alcohol, as well as the administration of various narcotics, also causes a marked increase in blood fats.

The chylomicrons are rapidly removed from the blood str in the adipose tissue, heart muscle and liver. In the adipose ti the triglycerides rapidly undergo considerable degradation, their constituent fatty acids are used for resynthesis of new glycerides and phospholipids and also for combustion to C Since the body's capacity to metabolize the fatty acids is limi drastic changes in the fatty-acid composition of dietary fats r affect that of the depot fats.

Depot fats. The principal locations of depot fats in the body subcutaneous, intramuscular, in the omentum, and in associat with various organs such as the heart, kidney, mesentery, ovar etc. Their main function is that of an energy reserve, for which p pose they are more efficient than carbohydrates or proteins. warm-blooded animals, subcutaneous fat often provides insulati against heat loss which is essential for survival. Adipose tissue a affords some protection against mechanical injury to import organs. In certain species, notably some marine animals, triglyc ides are almost entirely replaced as energy reserves by other lipi for example waxes. In any particular animal the amount of dep fat laid down is dependent on the state of nutrition and other f tors and it is being continuously utilized and replaced.

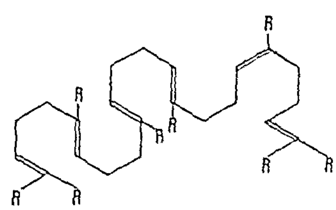
In addition to dietary fat, triglycerides synthesized in the bo itself are also stored, the fatty acids arising from carbohydrates a thus indirectly also from proteins, and the glycerol mainly fro the splitting of blood glucose.

Unsaponifiable matter of fats

Natural fats contain a proportion of *unsaponifiable matter* varyin from 0.1 to 5%. This consists chiefly of cholesterol and other sterol carotenoids (hydrocarbons related to carotene), and the fat-solub vitamins (see pages 457–469). The reasons for the occurrence c these substances in natural fats are presumably their solubility i triglycerides and insolubility in water. Many fats contain ster esters of fatty acids (see under 'Waxes', page 377) in addition t free sterols.

Cholesterol is a normal constituent of all animal tissues and major constituent of brain and nerve tissue in particular. Dietar cholesteryl esters are hydrolysed in the intestine and the free sterol i absorbed by the brush border. It is then transferred to the mucosa cells by a displacement mechanism, re-esterified and transported to the lymph[25]. Most of the body's cholesterol is synthesized endogenously, however, from acetyl-coenzyme A (see pages 426 to 427), principally in the liver. In the plasma, cholesterol circulates as a component of lipoproteins (see page 601).

The hydrocarbon *squalene* occurs in the liver oils of many elasmobranch fish, particularly sharks (up to 57% has been reported), also in olive oil, yeast fat and human skin. Its role as a precursor of cholesterol in the animal liver has been demonstrated (see page 426).



$(R = CH_3)$

Squalene

Alkoxydiglycerides

The liver oils of Elasmobranch fish contain considerable proportions of compounds differing from the triglycerides in containing an ether linkage. They are diglycerides in which the remaining hydroxyl group has formed an ether with a higher aliphatic alcohol ($R\cdot OH$) and may therefore be designated either as alkoxydiglycerides or as fatty acid esters of glyceryl ethers:

$CH_2\cdot O\,R$
$CH\,O\,CO\,R'$
$CH_2\cdot O\,CO\,R''$

Alkoxydiglycerides

Ratfish liver oil consists almost exclusively of such compounds and contains practically no triglycerides. Diglyceride ethers of α,β-unsaturated higher aliphatic alcohols occur in the plasmalogen fraction (see page 376).

(For references see page 377)

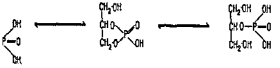
yceriCes

olipids (phosphatides)

lly speaking, the phospholipids (phosphatides) are esters acids in which the alcohol component of the molecule

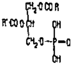
phosphatides

glycerophosphatides are of universal occurrence. Chemi-hey consist of α-glycerophosphoric acid esterified with fatty nd/or other constituents.



tro-oric acid | Glyceric-1,2-cyclic phosphoric acid | β Glycero-phosphoric acid

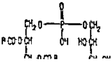
Phosphatidic acids Phosphatidic acids, the simplest of the ophosphatides and those most similar chemically to the tri-ides are derived from α-glycerophosphoric ...



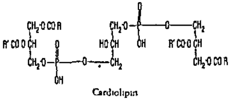
α Phosphatidic acids
(where R CO and R' CO are fatty acid residues)

osphatidic acids have been isolated from a wide range of plant

e consisting of triglycerides in which one of the ester residues phosphatidic acid[10]



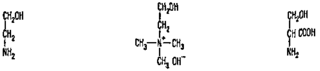
A phosphatidic acid derivative of importance is cardiolipin, which plays a role in the WASSERMANN reaction First isolated from heart muscle, it consists of an α,α'-diglyceride in which the ester residues are both phosphatidic acids[11].



Cardiolipin

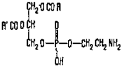
The fatty acids of cardiolipin consist almost entirely of oleic and linoleic acids in the ratio 1:5. *E. coli* is capable of forming cardiolipin from α-phosphatidylglycerols[12].

(*b*) *Phosphatidyl esters* These substances are phosphatidic acids esterified with the hydroxyl groups of ethanolamine, choline or serine:

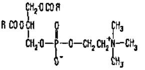


Ethanolamine | Choline | Serine

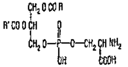
The resulting three types of phosphatidyl ester are



α-Phosphatidylethanolamines (cephalins)



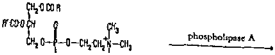
α-Phosphatidylcholines (lecithins)

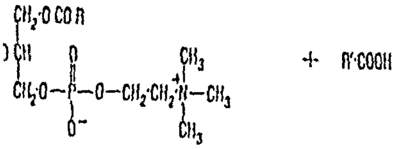


α Phosphatidylserines

The term 'cephalin' was originally given to an ethanol-insoluble ...

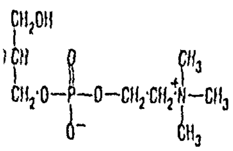
The lecithins obtained from many sources have all been shown to have the ...



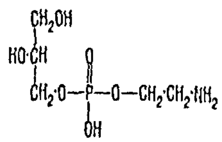


Lysolecithins   Fatty acid

(*d*) *α-Glycerophosphoryl compounds* that lack both of the fatty acids :esent in phosphatidyl esters occur in mammalian tissues and ıids[15]. They are α-glycerophosphorylethanolamine and α-glyc-ophosphorylcholine:

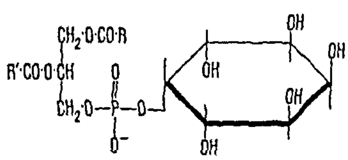


Glycerophosphorylcholine



α-Glycerophosphorylethanolamine

(*e*) *Phosphatidylinositides*[16]. At least three distinct inositides have en described. These have been differentiated on the basis of the ɔsitol derivatives obtained on hydrolysis. One type, the phos-ıatidylinositols (phosphoinositides)[17], are analogous to the glyc-ɔphosphatides. They occur in liver, heart, wheat germ and soy-an, and have the following structure:



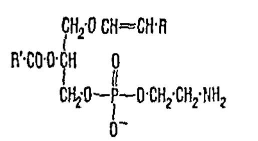
α-Phosphatidylinositols

Di- and triphosphoinositides have a similar structure with, in lition, either one or two phosphoric acid groups esterified with : inositol moiety[18].

?hosphoinositides are important metabolically active compo-ıts of the myelin sheath, with a high turnover rate. They are ınd to neurokeratin and to peptides (phosphatidopeptides) con-ıing β-alanine[18].

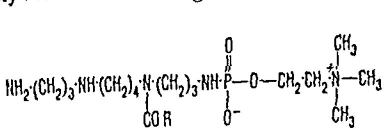
f) *Acetal phosphatides* (plasmalogens). These compounds are sely related to the phosphatidyl esters. Plasmalogens containing anolamine (phosphatidal ethanolamine) predominate in nature, : compounds in which ethanolamine is replaced by either serine ıosphatidal serine) or choline (phosphatidal choline) are also lely distributed in many tissues. Phosphatidal ethanolamine is major ethanolamine-containing lipid of myelin.

'lasmalogens give a positive reaction for aldehydes, and the :hydes corresponding to stearic and palmitic acids have been lated from the crystalline acetal phosphatides of brain. About different aldehydogenic chains occur in plasmalogens, 25–35% them branched[18]. They have been shown[19] to contain two g-chain alkyl groups, one of which is present in ester linkage l the other in an unsaturated vinyl ether linkage:



Acetal phosphatides (plasmalogens)

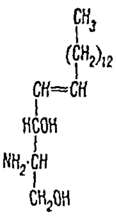
'he existence of a phospholipid in malignant tumours has been ɔrted. The compound, which possesses a marked affinity for toporphyrin III, is composed of choline, spermine, phosphoric l and fatty acid. The following structure has been proposed[20]:



(*g*) *Alkyloxylysophosphatides*[21]. Analogues of acetal phosphatid with a saturated α,β-bond in the ethereal alkyl group, occur myelin and other tissues. They may be regarded as alkyl ethers lysophosphatides, e.g., glycerol 1-hexadecyloxy-2-acyl-3-phosph rylethanolamine. They lack aldehydogenic properties, resist son hydrolytic procedures, and are important components of the ceph lin B complex of glycerophosphatides, which is difficult to separa from sphingomyelin.

Sphingolipids

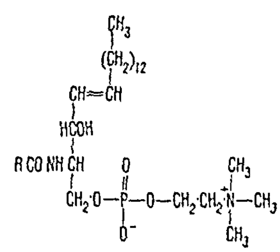
In the sphingolipid group, the base sphingosine (*erythro-trans*-1,3 dihydroxy-2-aminooctadec-4-ene) replaces glycerol. A single fatt acid radical is attached to the nitrogen by an amide linkage; th acylsphingosines are known as *ceramides*. Some sphingolipids ar phosphatides, but others contain no phosphorus.



Sphingosine

In some members of the sphingolipid group, sphingosine is replaced by dihydrosphingosine (in which the double bond of sphingosine is saturated), or by the 4-hydroxy derivative of dihydrosphingosine (1,3,4-trihydroxy-2-amino-octadecane), phytosphingosine or its C_{20} homologue.

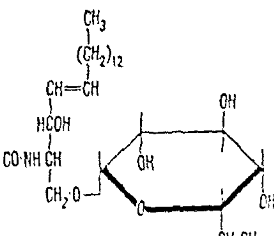
(*a*) *Sphingomyelin*. The only sphingolipids resembling the glycerophosphatides are the sphingomyelins:



Sphingomyelins

Sphingomyelin is an important component of the myelin sheath. The sphingomyelin of grey matter contains mainly stearic acid[22], that of white matter mainly $C_{24:1}$ acid with lesser amounts of $C_{23:1}$, $C_{26:1}$, C_{24}, C_{25} and C_{18} acids.

(*b*) *Cerebrosides*[26]. Cerebrosides are widely distributed in nature. They consist of ceramide attached by a β-glycosidic linkage to a sugar, usually galactose or glucose but sometimes a di- or trisaccharide. Myelin contains large amounts of galactocerebrosides (ceramide galactoside), separable into four classes on the basis of the fatty acid linked to sphingosine. A proportion of each galactocerebroside contains dihydrosphingosine in place of sphingosine.



Cerebrosides

Other fatty acids, ranging from C_{14} to C_{26}, as well as the corresponding α-hydroxy acids, also occur[23,25]. The α-hydroxy acids constitute 50–60% of the total fatty acids.

Cerebroside	Constituent fatty acid
Kerasin	Lignoceric acid $CH_3 \cdot (CH_2)_{22} \cdot COOH$
Phrenosin	Cerebronic acid $CH_3 \cdot (CH_2)_{21} \cdot CH(OH) \cdot COOH$
Nervone	Nervonic acid $CH_3 \cdot (CH_2)_7 \cdot CH = CH \cdot (CH_2)_{13} \cdot COOH$
Hydroxynervone	Hydroxynervonic acid $CH_3 \cdot (CH_2)_7 \cdot CH = CH \cdot (CH_2)_{12} \cdot CH(OH) \cdot COOH$

In Tay-Sachs' disease (see page [illegible]) the [illegible]

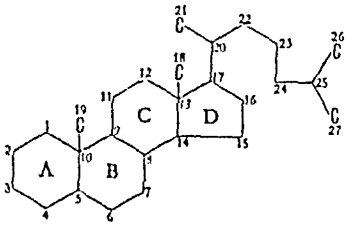
Waxes

The saponifiable waxes (as distinct from the hydrocarbon [illegible] are conveniently divisible into the so-called *true waxes*, whi[illegible] long-chain fatty-acid esters of long-chain aliphatic alcohol[illegible] [illegible]

Steroids[1]

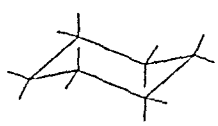
Stereochemistry

The naturally occurring steroids include the sex hormones, the adrenocortical hormones and progesterone as well as cholesterol and the bile acids. All steroids possess the cyclopentanoperhydrophenanthrene ring system, a fairly flat structure conveniently represented as planar:



Cyclopentanoperhydrophenanthrene ring system

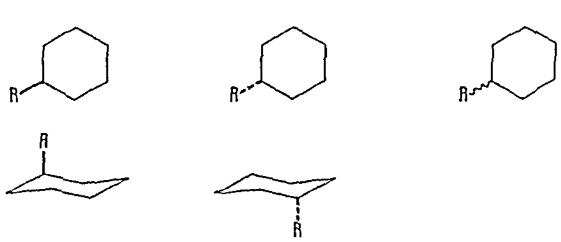
The skeleton (nucleus) of the steroid molecule consists of three six-membered rings A, B and C and a five-membered ring D. Each of the six-membered rings is in the 'chair' conformation:



'Chair' conformation

There may be methyl or other groups at C-10 and C-13 and a side chain at C-17 of up to eight carbons. In the oestrogens ring A is aromatic. The system of numbering is shown in the figure above.

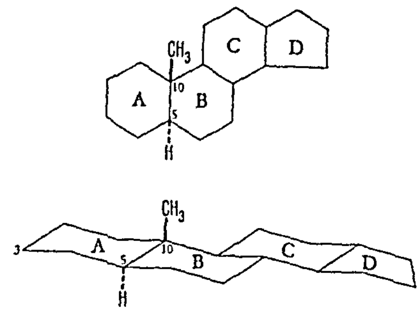
In these structures all the carbon atoms shared by two rings are asymmetric and, in addition, replacement of hydrogen atoms on other carbon atoms by other monovalent groups introduces further asymmetry. Since the biological activity of steroids is dependent on the stereochemical configuration it is essential to give precise designations. In the skeleton as shown in the figure the side nearer the observer is designated 'β' and the other side 'α'; thus in cholesterol the hydroxyl group projects towards the observer from the plane of the steroid skeleton when arranged as in the figure and so is 'above' it and thus 'β'. The systematic name for cholesterol is therefore cholest-5-en-3β-ol. In structural formulae, groups with β configuration are shown as attached to the steroid skeleton by a continuous line (——), those with α configuration by a dotted or broken line (- - -). Groups of unknown configuration are shown attached by a wavy line (~~~) and designated in names by the Greek letter. The prefix 'epi-' is used trivially to indicate inversion



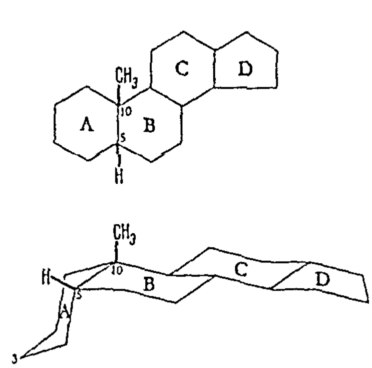
β configuration (R above the plane of the ring) | α configuration (R below the plane of the ring) | ξ configuration (configuration unknown)

of a substituent; thus the more common natural form of oestradiol is the 17β-hydroxy compound (17β-oestradiol) while the less common 17α-hydroxy form is often referred to as 17-epioestradiol or simply epioestradiol.

There are two distinct series of naturally occurring steroids saturated at C-5 which differ in their stereochemistry at the junction of the A and B rings. The series in which the A:B junction is *trans* is designated '5α' because the hydrogen attached to C-5 is on the α side and is *trans* with respect to the methyl group attached to C-10. The series in which the A:B junction is *cis* is designated '5β' because the hydrogen attached to C-5 is on the β side and is *cis* with respect to the methyl group attached to C-10. In steroids unsaturated at C-5, i.e., with a double bond between C-4 and C-5

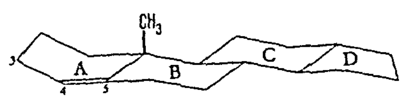


5α series of steroids saturated at C-5



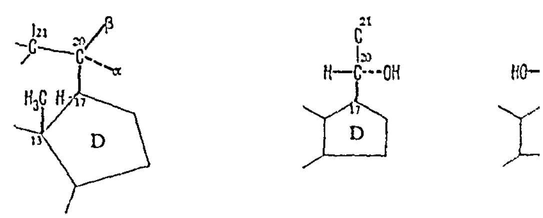
5β series of steroids saturated at C-5

or between C-5 and C-6, there is no hydrogen at C-5 and l stereoisomerism at the A:B ring junction. The prefix 'allo-' merly used to denote the 5α configuration. The C_{27} steroi ton with 5α configuration was formerly called coprostane v 5β configuration was called cholestane; the names 5α-ch and 5β-cholestane are now used. The C_{19}-steroid skeleton configuration was formerly called androstane while the 5β uration was called aetiocholane or aetiane; they are now as 5α-androstane and 5β-androstane.



Δ^4-Steroids

The symbols α and β are also used to denote stereoisome C-20. For this purpose the carbon atoms C-20 and C- assumed to lie in a plane parallel to and above the skeleton; valent groups attached to C-20 may then be either above thi (β) or below it (α).



20α-Hydroxy- 20β-Hy

Classification

Steroids are classified both by the total number of carbon : in the molecule and according to their function (see opposit

C_{17}-*Steroids* — parent compound *gonane*; no groups at C-10, or C-17.

C_{18}-*Steroids* — parent compound *oestrane*; methyl group at and no side chain at C-17; include the naturally occurring oc gens.

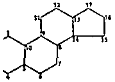
C_{19}-*Steroids* — parent compound *androstane*; methyl groups at and C-13 but no side chain at C-17; include the naturally o ring androgens.

Steroids — parent compound *pregnane*; methyl groups at C-10 ıd C-13 and a 2-carbon side chain at C-17, include the naturally :curring corticosteroids

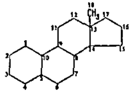
Steroids — parent compound *cholane*, methyl groups at C-10 and -13 and a branched 5-carbon side chain at C-17, include many aturally occurring bile acids

Steroids — parent compound *cholestane*, methyl groups at C-10 ıd C-13 and a branched 8-carbon side chain at C-17, e g, cho-:sterol.

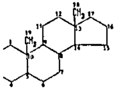
!ames of parent compounds of other naturally occurring steroids *rgostane* (24-methyl-5α-cholestane), *stigmastane* (24-ethyl-5α-cho-ıne), *lanostane* (4,4,14α-trimethyl-5α-cholestane)



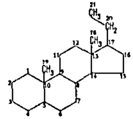
Gonane



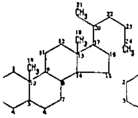
Oestrane



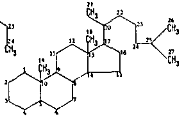
Androstane



Pregnane



Cholane



Cholestane

ble 21 Prefixes and suffixes in steroid nomenclature

Chemical group	Prefix	Suffix
louble bond	Δ (in trivial names only)	changes -ane to *-ene*
riple bond	–	changes -ane to *-yne*
ıydroxyl	hydroxy-	-ol
ıcetate ester	acetoxy-	-yl acetate
enzoate ester	benzoyloxy-	-yl benzoate
ulphate ester	–	-yl sulphate
glucuronoside (glucuronide)	–	-glucuronide
carbonyl	oxo- (formerly keto-)	-one
ıldehyde	–	-al
carboxylic acid	carboxy-	-oic acid
amine	amino	-amine
halogen (e g, chlorine)	halogeno- (e g, chloro-)	halide (e g, chloride, in trivial names only)
epoxide	epoxy-	–
ethyne (-C ≡ CH)	ethynyl-	–

Systematic nomenclature

Steroids are named systematically[2] by adding prefixes and suffixes to the names of the parent hydrocarbons The Greek letter Δ was formerly used to denote an olefinic double bond and is still

monal activity.

Prefixes and suffixes used in steroid nomenclature are listed in Table 21.

Other *prefixes* in trivial or systematic use are

allo- (in trivial names): formerly used to denote the 5α-series of saturated steroids

anhydro- (in trivial names): loss of H and OH from adjacent carbon atoms with formation of a double bond

dehydro- (in trivial names). loss of 2H from adjacent carbon atoms with formation of a double bond

deoxy- or *desoxy-* (in trivial names): replacement of OH by H

de-· removal of a whole ring, e g, de-D

dihydro- (in trivial names): addition of 2H to a double bond

epi- (in trivial names)· inversion of a substituent from α to β or from β to α

homo-. ring enlargement, e g, D-homo- means a six membered D ring

nor- (preceded by carbon number or ring letter). removal of one carbon atom

seco- ring fission with addition of one H to each of the two terminal groups (preceded by the numbers of the atoms forming the bond cleaved)

Steroid hormones

Steroid hormones are found in all classes of vertebrates[3] and

Table 22 Names, formulae and hormonal activity of important steroids

Trivial name	Systematic name	Formula (mol.wt.)	Hormonal activity*
Adrenosterone	Androst-4-ene-3,11,17-trione	$C_{19}H_{24}O_3$ (300.40)	♂
Aetianedione (aetiocholanedione)	5β-Androstane-3,17-dione	$C_{19}H_{28}O_2$ (288.43)	–
Aetiocholanolone	3α-Hydroxy-5β-androstan-17-one	$C_{19}H_{30}O_2$ (290.45)	–
3β-Aetiocholanolone	3β-Hydroxy-5β-androstan-17-one	$C_{19}H_{30}O_2$ (290.45)	–
Aldosterone	11β,21-Dihydroxypregn-4-en-18-al-3,20-dione	$C_{21}H_{28}O_5$ (360.45)	*G*, *M*
Allocortol	5α-Pregnane-3α,11β,17α,20α,21-pentol	$C_{21}H_{36}O_5$ (368.52)	–
β-Allocortol	5α-Pregnane-3α,11β,17α,20β,21-pentol	$C_{21}H_{36}O_5$ (368.52)	–
Allocortolone	3α,17α,20α,21-Tetrahydroxy-5α-pregnan-11-one	$C_{21}H_{34}O_5$ (366.50)	–
β-Allocortolone	3α,17α,20β,21-Tetrahydroxy-5α-pregnan-11-one	$C_{21}H_{34}O_5$ (366.50)	–
α-Allopregnanediol	3α,20α-Dihydroxy-5α-pregnane	$C_{21}H_{36}O_2$ (320.52)	–
β-Allopregnanediol	3β,20α-Dihydroxy-5α-pregnane	$C_{21}H_{36}O_2$ (320.52)	–
α-Allopregnanolone	3α-Hydroxy-5α-pregnan-20-one	$C_{21}H_{34}O_2$ (318.50)	–
Allotetrahydrocortisol	3α,11β,17α,21-Tetrahydroxy-5α-pregnan-20-one	$C_{21}H_{34}O_5$ (366.50)	–
Androstanedione	5α-Androstane-3,17-dione	$C_{19}H_{28}O_2$ (288.43)	♂
Androstenedione	Androst-4-ene-3,17-dione	$C_{19}H_{26}O_2$ (286.42)	♂
Androsterone	3α-Hydroxy-5α-androstan-17-one	$C_{19}H_{30}O_2$ (290.45)	♂
*Betamethasone***	9α-Fluoro-11β,17,21-trihydroxy-16β-methylpregna-1,4-diene-3,20-dione	–	*G*, *A*
Cholecalciferol	See Vitamin D_3		
Cholesterol	Cholest-5-en-3β-ol	$C_{27}H_{46}O$ (386.67)	–
Cortexolone	See 11-Deoxycortisol		
Cortexone	See Deoxycorticosterone		
Corticosterone (compound B)	11β,21-Dihydroxypregn-4-ene-3,20-dione	$C_{21}H_{30}O_4$ (346.47)	*G*, *M*
Cortisol (hydrocortisone, 17α-hydroxy-corticosterone, compound F)	11β,17α,21-Trihydroxypregn-4-ene-3,20-dione	$C_{21}H_{30}O_5$ (362.47)	*G*, *A*, *M*
Cortisone (compound E)	17α,21-Dihydroxypregn-4-ene-13,11,20-trione	$C_{21}H_{28}O_5$ (360.45)	*G*, *A*, *M*
α-Cortol	5β-Pregnane-3α,11β,17α,20α,21-pentol	$C_{21}H_{36}O_5$ (368.52)	–
β-Cortol	5β-Pregnane-3α,11β,17α,20β,21-pentol	$C_{21}H_{36}O_5$ (368.52)	–
α-Cortolone	3α,17α,20α,21-Tetrahydroxy-5β-pregnan-11-one	$C_{21}H_{34}O_5$ (366.50)	–
β-Cortolone	3α,17α,20β,21-Tetrahydroxy-5β-pregnan-11-one	$C_{21}H_{34}O_5$ (366.50)	–
11-Dehydrocorticosterone (compound A)	21-Hydroxypregn-4-ene-3,11,20-trione	$C_{21}H_{28}O_4$ (344.45)	*G*
Dehydroepiandrosterone (dehydro*iso*androsterone, androstenolone)	3β-Hydroxyandrost-5-en-17-one	$C_{19}H_{28}O_2$ (289.44)	♂
Deoxycorticosterone (11-deoxycorticosterone, DOC, cortexone, 21-hydroxypregnenolone)	21-Hydroxypregn-4-ene-3,20-dione	$C_{21}H_{30}O_3$ (330.47)	*G*
11-Deoxycortisol (cortexolone, substance S)	17α,21-Dihydroxypregn-4-ene-3,20-dione	$C_{21}H_{30}O_4$ (346.47)	*G*
21-Deoxycortisol	11β,17α-Dihydroxypregn-4-ene-3,20-dione	$C_{21}H_{30}O_4$ (346.47)	–
*Dexamethasone***	9α-Fluoro-16α-methyl-11β,17α,21-trihydroxypregna-1,4-diene-3,20-dione	$C_{22}H_{29}FO_5$ (392.47)	*A*, *G*
Epiandrosterone (*iso*androsterone)	3β-Hydroxy-5α-androstan-17-one	$C_{19}H_{30}O_2$ (290.45)	♂

* *A* Anti-inflammatory activity; *G* Glucocorticoid activity; *M* Mineralocorticoid activity; *P* Progestational activity; ♂ Androgenic activity; ♀ Oestrogenic activity

** Synthetic steroid; no known natural occurrence.

Table 22 Names, formulae and hormonal activity of important steroids

Trivial name	Systematic name	Formula (mol wt)	Hormonal activity*
Epioestradiol (17-epioestradiol, oestradiol-17α)	Oestra-1,3,5(10)-triene-3,17α-diol	$C_{18}H_{24}O_2$ (272.39)	♀
Epitestosterone	17α-Hydroxyandrost-4-en-3-one	$C_{19}H_{28}O_2$ (288.43)	–
Equilenin	3-Hydroxyoestra-1,3,5(10),6,8-penten-17-one	$C_{18}H_{18}O_2$ (266.34)	♀
Equilin	3-Hydroxyoestra-1,3,5(10),7-tetraen-17-one	$C_{18}H_{20}O_2$ (268.36)	♀
Ergocalciferol	See Vitamin D_2		
Ergosterol	24-Methylcholesta-5,7,22-trien-3β-ol	$C_{28}H_{44}O$ (396.66)	–
*Ethynyloestradiol***	17α-Ethynyloestra-1,3,5(10)-triene-3,17β-diol	–	♀
*Fluorocortisol*** (9α-fluorocortisol, 9α-fluorohydrocortisone)	9α-Fluoro-11β,17α,21-trihydroxypregn-4-ene-3,20-dione	–	*A*, *M*
*Fluorometholone*** (oxylone)	9α-Fluoro-6α-methyl-11β,17α-dihydroxypregna-1,4-diene-3,20-dione	–	*A*
*Fluoxymestrone***	9α-Fluoro-11β,17β-dihydroxy-17α-methylandrost-4-en-3-one	–	♂
17-α-Hydroxyprogesterone	17α-Hydroxypregn-4-ene-3,20-dione	$C_{21}H_{30}O_3$ (330.47)	♂, *P*
20α-Hydroxyprogesterone	20α-Hydroxypregn-4-en-3-one	$C_{21}H_{32}O_2$ (316.49)	*P*
20β-Hydroxyprogesterone	20β-Hydroxypregn-4-en-3-one	$C_{21}H_{32}O_2$ (316.49)	*P*
Lanosterol	4,4,14α-Trimethylcholesta-8,24-dien-3β-ol	$C_{30}H_{50}O$ (426.73)	–
*Methylprednisolone***	6α-Methyl-11β,17α,21-trihydroxypregna-1,4-diene-3,20-dione	$C_{22}H_{30}O_5$ (374.48)	*A*, *M*
*Norethandrolone***	17α-Ethyl-17β-hydroxy-19-norandrost-4-en-3-one	–	♂***
*Norethindrone*** (norethisterone)	17α-Ethynyl-17β-hydroxy-19-norandrost-4-en-3-one	–	*P*
*Norethynodrel***	17α-Ethynyl-17β-hydroxyoestr-5(10)-en-3-one	–	*P*
Oestradiol (oestradiol-17β)	Oestra-1,3,5(10)-triene-3,17β-diol	$C_{18}H_{24}O_2$ (272.39)	♀
Oestriol	Oestra-1,3,5(10)-triene-3,16α,17β-triol	$C_{18}H_{24}O_3$ (288.39)	♀
Oestrone	3-Hydroxyoestra-1,3,5(10)-trien-17-one	$C_{18}H_{22}O_2$ (270.37)	♀
*Prednisolone***	11β,17α,21-Trihydroxypregna-14-diene-3,20-dione	$C_{21}H_{28}O_5$ (360.45)	*A*, *M*
*Prednisone***	17α,21-Dihydroxypregna-1,4-diene-3,11,20-trione	$C_{21}H_{26}O_5$ (358.44)	*A*, *M*
Pregnanediol	5β-Pregnane-3α,20α-diol	$C_{21}H_{36}O_2$ (320.52)	–
Pregnanetriol	5β-Pregnane-3α,17α,20α-triol	$C_{21}H_{36}O_3$ (336.52)	–
Pregnanolone	3α-Hydroxy-5β-pregnan-20-one	$C_{21}H_{34}O_2$ (318.50)	–
Pregnenolone (Δ^5-pregnenolone)	3β-Hydroxypregn-5-en 20-one	$C_{21}H_{32}O_2$ (316.49)	–
Progesterone	Pregn-4-ene-3,20-dione	$C_{21}H_{30}O_2$ (314.47)	*P*
Testosterone	17β-Hydroxyandrost-4-en-3-one	$C_{19}H_{28}O_2$ (288.43)	♂
Tetrahydro-A	3α,21-Dihydroxy-5β-pregnane-11,20-dione	$C_{21}H_{32}O_4$ (348.49)	–
Tetrahydro-B	3α,11β,21-Trihydroxy-5β-pregnan-20-one	$C_{21}H_{34}O_4$ (350.50)	–
Tetrahydro-E	See Urocortisone		
Tetrahydro-F	See Urocortisol		
Tetrahydro-S	3α,17α,21-Trihydroxy-5β-pregnan-20-one	$C_{21}H_{34}O_4$ (350.50)	–
*Triamcinolone***	9α-Fluoro-11β,16α,17α,21-tetrahydroxypregna-1,4-diene-3,20-dione	$C_{21}H_{27}FO_6$ (394.44)	*A*
Uroaldosterone	3α,11β,21-Trihydroxy-20-oxo-5β-pregnan-18-al	$C_{21}H_{32}O_5$ (364.49)	–
Urocortisol (tetrahydro-F)	3α,11β,17α,21-Tetrahydroxy-5β-pregnan-20-one	$C_{21}H_{34}O_5$ (366.50)	–
Urocortisone (tetrahydro-E)	3α,17α,21-Trihydroxy-5β-pregnane-11,20-dione	$C_{21}H_{32}O_5$ (364.49)	–
Vitamin D_2 (ergocalciferol)	24-Methyl-9,10-secocholesta-5,7,10(19),22-tetraen-3β-ol	$C_{28}H_{44}O$ (396.66)	–
Vitamin D_3 (cholecalciferol)	9,10-Secocholesta-5,7,10(19)-trien-3β-ol	$C_{27}H_{44}O$ (384.65)	–

* *A* Anti inflammatory activity; *G* Glucocorticoid activity; *M* Mineralocorticoid activity; *P* Progestational activity; ♂ Androgenic activity; ♀ Oestrogenic activity

** Synthetic steroid, no known natural occurrence
*** High anabolic activity, low androgenic activity

(For references see page 385)

Enzymes

Enzymes are protein catalysts ranging in molecular weight from about 13 000 (ribonuclease) up to as much as one million (pyruvate decarboxylase). They are purified and isolated by the use of techniques for fractionating proteins[1]. Their general properties will be described in the section which follows*.

Nomenclature of enzymes

Enzymes are usually given names indicating both the principal substrate and the reaction catalysed (e.g., malate dehydrogenase). Many enzymes have, however, been given trivial names and these are often a cause of confusion. With the aim of eliminating the existing ambiguity, the Commission on Enzymes of the International Union of Biochemistry has worked out a systematic nomenclature[2] based on the reaction catalysed (see Table 24, page 385) and has given each enzyme a characteristic number indicating the nature of this reaction together with a recommended trivial name (these names have been used in the chapter on 'Metabolism' on pages 387–445).

The word 'enzyme' usually denotes a catalytic protein plus any component that cannot be readily removed from the protein without denaturing it. The usage is not very rigid, however, for in some contexts 'enzyme' is intended to include dissociable cofactors and in others to indicate the catalytic protein *per se*. If there is danger of ambiguity, the catalytic protein is denoted by the term '*apo-enzyme*' and the protein plus cofactors by '*holo-enzyme*'.

Coenzymes or *prosthetic groups* are nonprotein organic compounds which, in combination with the apo-enzyme, play an intimate part in the catalysis by the enzyme. There is no generally accepted distinction between coenzymes and prosthetic groups, but the latter name is usually reserved for groups that are bound relatively firmly by the protein. '*Activators*' are usually distinguished from coenzymes in being small ions that are required by some enzymes for full catalytic activity. Some enzymes do not appear to possess a prosthetic group or coenzyme nor do they require an activator.

Specificity of enzymes[3]

Although nearly all the individual reactions of intermediary metabolism are catalysed by separate enzymes (see pages 405–419), few of these enzymes are absolutely specific to the structure of their substrates. Most enzymes can act on close structural analogues of their physiological substrates, although usually at much reduced rates, whilst a few enzymes can act on a relatively wide group of substrates. Like any other catalyst, an enzyme catalyses both the forward and reverse reactions, but does not affect the final position of the equilibrium.

There are no completely general rules of enzyme specificity, for in different enzyme systems different parts of the substrate molecule appear to be important. Thus, the lipases require an ester bond in their substrates but there can be very considerable variation in the structures of the groups adjoining this susceptible bond. On the other hand, chymotrypsin and trypsin require certain configurations in the neighbourhood of the susceptible bond, but the nature of the bond itself can vary. For example, these enzymes will hydrolyse peptide bonds in protein substrates but in certain artificial substrates (e.g., methyl cinnamate) ester bonds can be hydrolysed.

An added complication is that those hydrolytic enzymes which can act on several substrates are usually capable of catalysing a transferring reaction in which an alcohol or an amine replaces the water. Many of these transfer reactions are unlikely to be of physiological significance because of the prevalence of water molecules under physiological conditions.

Many enzymes show stereochemical specificity in being unable to attack geometrical or optical isomers of their substrates. Less specific enzymes such as the esterases can, however, attack stereochemical isomers although usually at reduced rates.

Structure of enzymes and mechanism of enzyme action

In 1963 the complete sequence of the 124 amino-acid residues, together with the position of the sulphur bridges in the chain, was established for bovine ribonuclease[4]. Since that time the amino-acid sequence of many other enzymes has been elucidated[22]. The three-dimensional structure (conformation) of a few enzymes (e.g., lysozymes, ribonuclease, α-chymotrypsin) in the crystalline s has been determined by X-ray diffraction[23]. In 1969 the first t synthesis of an enzyme, that of ribonuclease, was accomplishe

It is now clear that the full catalytic activity of an enzyme depe on the integrity of the three-dimensional structure of the fol polypeptide chain. Denaturation of the enzyme, with concomi destruction of the organization in the chain will usually resul loss of enzyme activity. The surface formed by the folding of chain in the native structure thus enables the substrate molecul combine with the enzyme at three or more points. Those ami acid residues which contribute towards the formation of enzyme–substrate complex and which take part in the cataly process together constitute the 'active site' of the enzyme[5]. T folding of the peptide chain thus brings amino-acid residues wh are remote from each other in sequence into close juxtaposition the active site. Although the complete structures are unknown, t amino-acid sequences near the active sites of many enzymes ha been determined (e.g., cytochrome c, trypsin, pancreatopeptidase phosphoglucomutase). Studies of this type reveal variations in t amino-acid sequences in the same enzyme from different speci (e.g., ribonuclease)[6]. Some enzymes, for example those involved biosynthetic pathways, appear to have two distinct active sites, o for combining with substrate and another for combining with inhibitor[7] which may regulate the biological action of the enzym It is suggested that the formation of a complex between the inhib tor and the enzyme induces a conformational change in the enzym structure that modifies the catalytic activity of the other active sit rendering the enzyme inactive. This class of proteins have bee called 'allosteric'[8].

Although there is no instance in which the mechanism of actio of an enzyme is fully understood, a large number of mechanism have been proposed[9]. The most attractive ideas involve the for mation of a covalently-bound enzyme–substrate compound i which nucleophilic or electrophilic attack on the substrate moiet is facilitated by the enzyme.

Enzyme kinetics[10]

When an enzyme is added to a suitable reaction mixture there is first a very short lag before a steady rate of reaction is attained[11]. This lag is so short that it is not detectable when the rate is obtained from measurements made at intervals of one minute or longer. Once established, the rate remains constant for a period which may sometimes be as long as several hours, although in other cases it may be only a few minutes. The rate of reaction begins to fall after this period because of reduced substrate concentration and/or the accumulation of products. This decrease in reaction rate is not easily analysed mathematically, and it is therefore usual to study only the constant reaction rate. The following discussion is confined to this constant reaction rate.

If the enzyme is susceptible to inhibition by excess substrate (see below) the rate may at first increase as the inhibition is relieved by removal of the substrate.

Enzyme concentration. The reaction rate is usually proportional to the concentration of enzyme. Strict linearity may not always be achieved experimentally, for instance because the enzyme preparation may contain a dissociable activator or inhibitor or the enzyme may be unstable at low concentrations. Alternatively, the reaction may have proceeded so far that the rate has already commenced to fall off at the highest enzyme concentrations.

Hydrogen-ion concentration. Most enzymes possess well-defined pH optima with appreciable activity over a range of only 2–3 pH units. Some enzymes are inhibited by one or other of the buffers in common use. It is therefore often worthwhile to compare the results in one buffer with those obtained in another type of buffer solution of the same pH range.

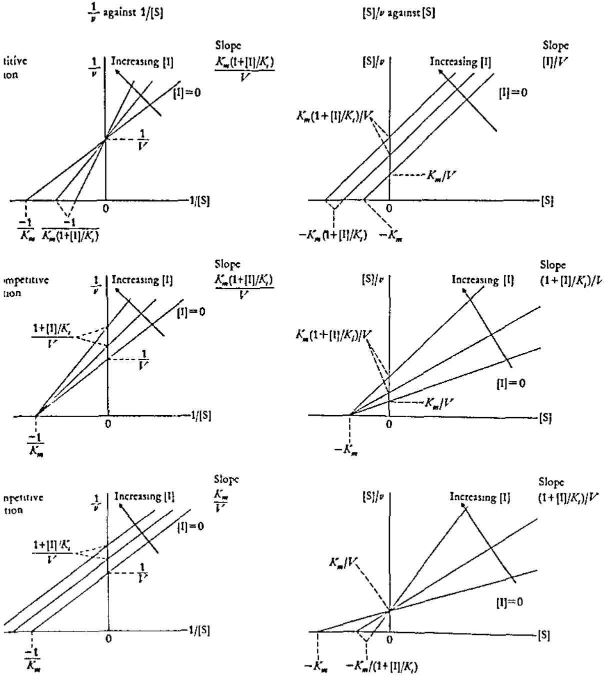
The study of kinetic data obtained at different pH values with different substrates and different concentrations of a single substrate is of use in investigating the details of enzyme mechanisms[12]. For other purposes, the variations in the pH curve with different substrates and substrate concentrations are not usually important.

Temperature. The rate of an enzyme-catalysed reaction increases by a factor which is usually 1.5–3 for every rise of 10°C. There is, however, an optimum temperature above which further increase reduces the amount of substrate reacting because the enzyme becomes inactivated. The optimum temperature for short-term experiments (e.g., of one hour's duration) is often about 50°C. Most

* The enzymes occurring in blood and various body tissues are described on pages 584–600, those responsible for digestion on pages 405–419. On enzyme units see page 584.

Inhibition data plotted according to Table 23

Each line represents data for a series of substrate concentrations One line of each graph is without inhibition and the other two are for two differe concentrations of inhibitor



nalian enzymes show little inactivation in the presence of cofactors and substrates at 37 °C, so that this is usually a ble temperature to study the reaction. It is not desirable to ise the temperature to the optimum because the rate of en inactivation, and therefore the optimum temperature, is often ly influenced by slight changes in the experimental conditions

strate concentration As the initial substrate concentration is ased, the rate of reaction is at first proportional to this con ation, but at higher values it usually becomes virtually in ndent of it This relation can be justified theoretically by con ing a mechanism such as

concentration of enzyme present. K_m is given by $(k_{-1} + k_2)/k_1$ and has the dimensions of concentration. Although K_m is independent of both [S] and e, it usually changes with pH, temperature, different substrates and the cofactor concentration. K_m may sometimes change with ionic strength or with different buffers and, like other characteristics of enzymes, it may differ for similar enzymes from different sources.

Equation (2) was first obtained theoretically by MICHAELIS and MENTEN[13], who assumed that the second reaction of mechanism (1) was the rate-limiting step. Under these conditions k_{-1} is much greater than k_2, and K_m becomes k_{-1}/k_1, which is the dissociation constant of the enzyme–substrate compound. This assumption is known to be valid for some enzymes but not for others[14].

Evaluation of Michaelis constant K_m and maximum velocity V. K_m may be evaluated by plotting the curve of v against [S]. The experimental data can, however, be used more efficiently by plotting certain functions of v and [S] as shown in Table 23[3,15]. These plots give straight lines if equation (2) is obeyed. The plot of $1/v$ against $1/[S]$ has the advantage that the variables are separate and the calculations for plotting are thus quicker. Unfortunately the points are not evenly spread and the errors at low values of v are accentuated. This method gives accurate values for V but less accurate estimates for K_m. A statistical evaluation[16] of the various graphical methods for determining K_m and V shows that the third method (Table 23) is the most satisfactory and gives the most accurate values of these quantities over the usual range of concentration and velocity available for experimentation.

Table 23 Linear plots for evaluating MICHAELIS constant K_m and maximum velocity V

Plot		Slope	Intercept	
Ordinate	Abscissa		Ordinate	Abscissa
$1/v$	$1/[S]$	K_m/V	$1/V$	$-1/K_m$
v	$v/[S]$	$-K_m$	V	V/K_m
$[S]/v$	[S]	$1/V$	K_m/V	$-K_m$

It is sometimes convenient, such as when comparing different substrates, to plot v against log [S]. This plot gives an S-shaped curve instead of a straight line; the inflection of this curve occurs at a value of log [S] equal to log K_m.

Inhibition by excess substrate. This phenomenon occurs with some enzymes and is usually explained by postulating that the enzyme–substrate compound (ES) combines with a second molecule of S to form an inactive complex which, unless it reverts to the original ES form, can yield products only slowly or not at all. When v is plotted against log [S], this mechanism predicts a symmetrical bell-shaped curve[17] if the rate can be reduced to zero by high substrate concentrations. This prediction agrees with experimental findings[18].

Another mechanism of substrate inhibition may occur if there is a dissociable cofactor such as Mg^{++} which can combine with the substrate. Increased substrate concentration may inhibit by removing the cofactor.

Inhibitors[15]. Two types of inhibition are commonly encountered, competitive and noncompetitive. In the competitive type, the inhibition is reduced by increasing the concentration of substrate. Many competitive inhibitors are structural analogues of the substrate, suggesting that the inhibitor and the substrate combine with the same site of the enzyme. Assuming that the inhibitor can react reversibly with the enzyme so as to prevent it combining with its substrate, it can be derived that on the basis of mechanism (1):

$$v = \frac{V[S]}{K_m(1 + [I]/K_i) + [S]} \tag{3}$$

where [I] is the concentration of inhibitor and K_i is the dissociation constant of the enzyme–inhibitor compound. V and K_m are the values obtained in the absence of the inhibitor.

In a case of noncompetitive inhibition, the amount of inhibition is independent of the concentration of substrate and depends only on the concentration of inhibitor. An equation to fit this can be derived by assuming that the inhibitor combines reversibly and equally readily with both the enzyme and the enzyme–substrate compound:

$$v = \frac{V[S]}{(K_m + [S])\,(1 + [I]/K_i)} \tag{4}$$

This mechanism suggests that a noncompetitive inhibitor does not combine with the active centre of the enzyme responsible for combination with the substrate.

It should be noted that, in competitive inhibition, the inhibitor increases the apparent MICHAELIS constant without affecting the maximum velocity, whereas in noncompetitive inhibition the inhibitor decreases the maximum velocity without changing the MICHAELIS constant.

A third and less common type of inhibition is that in which both the maximum velocity and the MICHAELIS constant are reduced to a similar extent, so that there is no change in the ratio K_m/V as evaluated from the plots of Table 23. This type of inhibition has been termed 'uncompetitive' and is illustrated by the action of azide on the oxidized form of cytochrome oxidase[19]. The appropriate equation is based on the assumption that the inhibitor combines only with the enzyme–substrate compound:

$$v = \frac{V[S]}{K_m + [S]\,(1 + [I]/K_i)} \tag{5}$$

Plotting inhibition data. The different types of inhibition can be clearly differentiated by using any of the substrate plots of Table 23 and thus determining the effect of the inhibitor on the apparent K_m or V. Examples are shown in Figure 7 (page 383). K_i can be evaluated from the quantitative nature of this effect. To show that

Fig. 8 Inhibition data: plots of $1/v$ against [I][3,15]

Each line represents data for a series of inhibitor concentrations [I] but at different substrate concentrations [S].

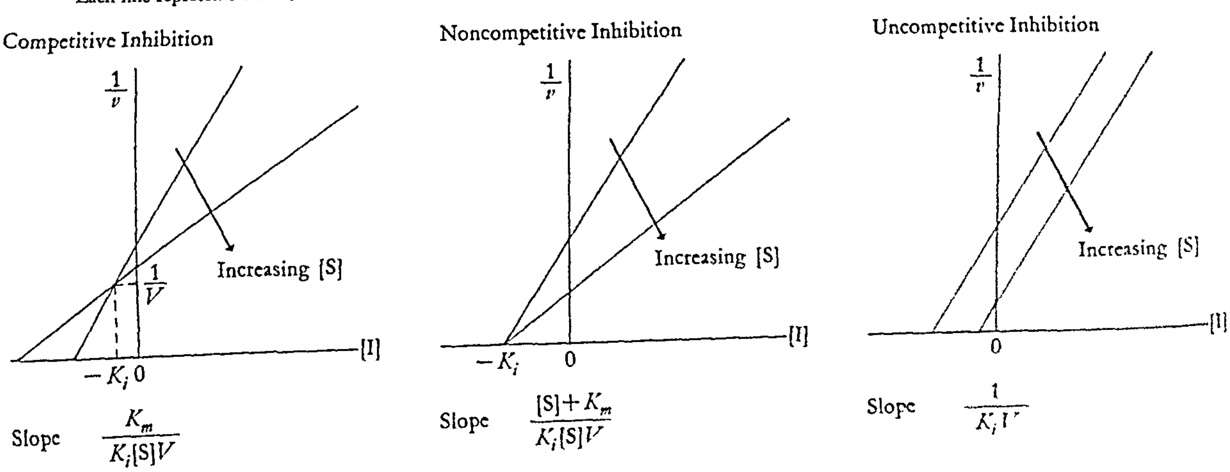


Table 24 (continued) Classification and numbering of enzymes

2. Transferases *(continued)*

2.4 Glycosyltransferases
- 2.4.1 Hexosyltransferases
- 2.4.2 Pentosyltransferases

2.5 Transferring alkyl or related groups

2.6 Transferring nitrogenous groups
- 2.6.1 *Aminotransferases*
- 2.6.3 Oximinotransferases

2.7 Transferring phosphorus-containing groups
- 2.7.1 Phosphotransferases with an alcohol group as acceptor
- 2.7.2 Phosphotransferases with a carboxyl group as acceptor
- 2.7.3 Phosphotransferases with a nitrogenous group as acceptor
- 2.7.4 Phosphotransferases with a phospho group as acceptor
- 2.7.5 *Phosphotransferases, apparently intramolecular*
- 2.7.6 Pyrophosphotransferases
- 2.7.7 Nucleotidyltransferases
- 2.7.8 Transferases for other substituted phospho groups

2.8 Transferring sulphur-containing groups
- 2.8.1 Sulphurtransferases
- 2.8.2 Sulphotransferases
- 2.8.3 *CoA-transferases*

3. Hydrolases

3.1 Acting on ester bonds
- 3.1.1 Carboxylic ester hydrolases
- 3.1.2 Thiolester hydrolases
- 3.1.3 *Phosphoric monoester hydrolases*
- 3.1.4 Phosphoric diester hydrolases
- 3.1.5 Triphosphoric monoester hydrolases
- 3.1.6 Sulphuric ester hydrolases

3.2 Acting on glycosyl compounds
- 3.2.1 Glycoside hydrolases
- 3.2.2 Hydrolysing *N*-glycosyl compounds
- 3.2.3 Hydrolysing *S*-glycosyl compounds

3.3 Acting on ether bonds
- 3.3.1 *Thioether hydrolases*

3.4 Acting on peptide bonds (peptide hydrolases)
- 3.4.1 α-Amino-acyl-peptide hydrolases
- 3.4.2 Peptidyl-amino-acid hydrolases
- 3.4.3 Dipeptide hydrolases
- 3.4.4 Peptidyl-peptide hydrolases

3.5 Acting on C–N bonds other than peptide bonds
- 3.5.1 *In linear amides*
- 3.5.2 In cyclic amides
- 3.5.3 In linear amidines
- 3.5.4 In cyclic amidines
- 3.5.5 In cyanides
- 3.5.99 *In other compounds*

3.6 Acting on acid-anhydride bonds
- 3.6.1 *In phosphoryl-containing anhydrides*

3.7 Acting on C–C bonds
- 3.7.1 *In ketonic substances*

3.8 Acting on halide bonds
- 3.8.1 In *C*-halide compounds
- 3.8.2 In *P*-halide compounds

3.9 Acting on P–N bonds

4. Lyases

4.1 Carbon–carbon lyases
- 4.1.1 Carboxy-lyases
- 4.1.2 Aldehyde-lyases
- 4.1.3 Ketoacid-lyases

4.2 Carbon–oxygen lyases
- 4.2.1 Hydro-lyases
- 4.2.99 Other carbon–oxygen lyases

4.3 Carbon–nitrogen lyases
- 4.3.1 Ammonia-lyases
- 4.3.2 *Amidine-lyases*

4.4 Carbon–sulphur lyases

4.5 Carbon–halide lyases

4.99 Other lyases

5. Isomerases

5.1 Racemases and epimerases
- 5.1.1 Acting on amino acids and derivatives
- 5.1.2 Acting on hydroxy acids and derivatives
- 5.1.3 Acting on carbohydrates and derivatives
- 5.1.99 Acting on other compounds

5.2 Cis-trans isomerases

5.3 Intramolecular oxidoreductases
- 5.3.1 Interconverting aldoses and ketoses
- 5.3.2 Interconverting keto and enol groups
- 5.3.3 *Transposing C=C bonds*

5.4 Intramolecular transferases
- 5.4.1 Transferring acyl groups
- 5.4.2 Transferring phosphoryl groups
- 5.4.99 Transferring other groups

5.5 Intramolecular lyases

5.99 Other isomerases

6. Ligases

6.1 Forming C–O bonds
- 6.1.1 Amino acid–RNA ligases

6.2 Forming C–S bonds
- 6.2.1 Acid–thiol ligases

6.3 Forming C–N bonds
- 6.3.1 Acid–ammonia ligases (amide synthetases)
- 6.3.2 Acid–amino-acid ligases (peptide synthetases)
- 6.3.3 Cyclo-ligases
- 6.3.4 Other C–N ligases
- 6.3.5 C–N ligases with glutamine as N donor

6.4 Forming C–C bonds

[1] International Union of Biochemistry, *Report of the Commission on Enzymes*, Pergamon Press, Oxford, 1961; International Union of Biochemistry, *E Nomenclature*, Recommendations 1964, Elsevier, Amsterdam, 1965.

So far little more than a beginning has been made in the biochemical analysis of disease The knowledge summarized in the following pages represents a foundation upon which molecular pathology will develop

Energy metabolism

The need for energy springs from the fact that living matter is a thermodynamically unstable system that cannot be maintained unless energy is continuously added Moreover, living matter is constantly engaged in performing various kinds of work, such as movement, chemical syntheses and transporting substances against concentration gradients Activities of this kind cannot take place unless there is a supply of energy Warm-blooded organisms need energy also to maintain the body temperature

$$C_6H_{12}O_6 \longrightarrow 2\ CH_3CH(OH)COOH$$

Micro-organisms possess many forms of fermentation, among which the most important is the alcoholic fermentation

$$C_6H_{12}O_6 \longrightarrow 2\ CH_3CH_2OH + 2\ CO_2$$

Cell metabolism

The metabolism of the whole body is the result of the metabolic activities of the component tissues Within the last 40 years methods have become available for the study of the metabolic activities of isolated tissues and organs In particular, measurements have been made of the rate of respiration and lactic acid fermentation of many types of cells and tissues A few representative figures for animal tissues are given in Tables 1 and 2

Table 1 Rate of respiration (Q_{O_2}) of animal tissues*

Representative values, measured on isolated tissues, usually slices suspended in glucose–saline medium at 38–40 °C. Unless otherwise stated the data refer to rat tissues For further data see the literature[7].

Tissue	Q_{O_2}	*Tissue*	Q_{O_2}
Kidney cortex ..	−25	Rous sarcoma (chicken)	− 5
Kidney medulla (guinea-pig)	− 8	Flexner's carcinoma .	− 8
Liver	−13	Erythrocytes . ..	− 0 6
Brain cortex .	−12	Leucocytes	− 9
Brain, white matter	− 6	Thrombocytes	− 7
Retina	−30	Bone marrow, red . ..	−10
Spleen	−12	Adipose tissue**	− 0 5
Lung	− 8	Connective tissue (renal capsule, goat)	− 1
Submaxillary gland	−12	Cartilage (costal)	− 0 5
Pancreas	− 4	Skin (newborn rat) . ..	− 1
Intestinal mucosa	−12	Striated muscle	
Colonic mucosa	−10	– diaphragm .	− 7
Adrenal gland .	−10	– gastrocnemius .	− 3
Pituitary gland	−12	– breast muscle (pigeon, minced)	−40
Thymus gland	− 5	Smooth muscle (gizzard, pigeon)	− 4
Thyroid (guinea-pig)	− 8	Cardiac muscle (sheep, minced)	−18
Testis	−10		
Jensen's sarcoma	−11		

* The magnitude of respiration and fermentation is commonly expressed by the 'metabolic quotients', defined as follows

$$Q_{O_2} = \frac{\text{microlitres of } O_2 \text{ used}}{\text{milligrammes dry weight} \times \text{hours}}$$

$$Q_{CO_2} = \frac{\text{microlitres of } CO_2 \text{ used or produced}}{\text{milligrammes dry weight} \times \text{hours}}$$

$$Q_{\text{lactic acid}} \text{ or } Q_L = \frac{\text{microlitres of lactic acid formed}}{\text{milligrammes dry weight} \times \text{hours}}$$

The disappearance of a substance is usually indicated by a negative sign, the formation by a positive sign Anaerobic and aerobic conditions are denoted by the superscripts N_2 and O_2 e g Q^{N_2}, Q^{O_2}

Table 2 Rate of anaerobic lactic acid fermentation ($Q^{N_2}_{\text{lactic acid}}$) in animal tissues*

Representative values, measured on isolated tissues, usually slices suspended in glucose-saline medium at 38–40 °C. Unless otherwise stated the data refer to rat tissues. For further data see the literature [1].

Tissue	$Q^{N_2}_{L}$	*Tissue*	$Q^{N_2}_{L}$
Kidney cortex	3	Testis	8
Kidney medulla (guinea-pig)	28	JENSEN's sarcoma	32
Liver	3	Rous sarcoma (chicken)	30
Brain cortex	18	FLEXNER's carcinoma	30
Retina	88	Erythrocytes	0.35
Retina (pigeon)	180	Leucocytes (polymorphonuclear, rabbit)	22
Spleen	8	Leucocytes (mononuclear, rabbit)	22
Lung (rat embryo)	10	Thrombocytes	26
Submaxillary gland	5	Bone marrow, red	21
Pancreas (rabbit)	3.5	Adipose tissue**	0.7
Intestinal mucosa	14	Cartilage (costal)	1.5
Adrenal gland	4	Skin (newborn rat)	7
Pituitary gland	13	Embryo	12
Thymus gland	8		

* See footnote * to Table 1, page 387.
** Calculated for dry weight less ether-soluble matter.

[1] KREBS and JOHNSON, *Tab. biol. (Amst.)*, 19, 100 (1948); ALBRITTON, E.C. (Ed.), *Standard Values in Nutrition and Metabolism*, Saunders, Philadelphia, 1954.

There are wide variations in the metabolic activities of diffe materials. The highest rates of respiration and fermentation found among micro-organisms. *Azotobacter*, for example, at 3 can give Q_{O_2} values of over 8000, and rates of 100–200 are c mon among bacteria. Anaerobic fermentation rates in micro-or isms reach figures up to 400. The maximum rate of lactic production in muscle can probably reach $Q^{N_2}_{L}$ values of well 100 for short periods. Avian retina gives the highest contin rate of lactic acid production among animal tissues ($Q^{N_2}_{L}$ = 18 pigeon retina).

Low metabolic rates are generally found in tissues of relati low physiological activity. This is true for resting glands or mu and in particular for tissues whose function, like that of connec tissue or bone, is largely structural or, like that of adipose tis is concerned with the storage of metabolically inert material.

The rates of respiration and fermentation increase with temp ture, like the majority of other chemical reactions. At a crit temperature – in the case of warm-blooded animals at about 40 in the case of cold-blooded animals somewhat below this temp ture – a further rise in temperature reduces metabolism. In exc tional cases, those of the thermophilic bacteria, the critical te perature may be as high as 80 °C.

Among the factors which affect energy production in the int warm-blooded animal, body size has long been recognized as be of major importance. The differences in the oxygen consumpti of intact animals of different size are not exactly reflected in rates of respiration of individual tissues. In general, the tissues larger species have a somewhat lower metabolism than the tiss of smaller species, but the differences between the Q_{O_2} values for example, brain, kidney, liver, spleen and lung of different s cies are relatively small. The characteristic differences in the ba metabolic rate of animals of different size appear to be due mai to differences in the resting metabolism of the musculature.

Energy-supplying reactions

Digestion is brought about by the combined action of many specific enzymes each dealing with the hydrolysis of one compound or of a series of closely related compounds The basic ... ecties of these enzymes are described on pages 405–419

Intermediary stages of carbohydrate degradation

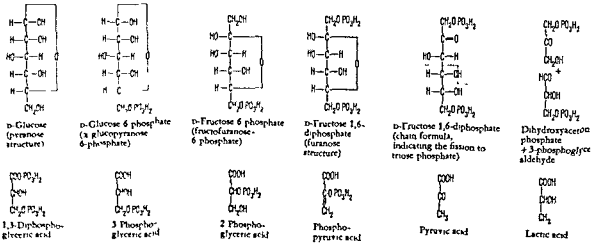
Hexoses formed by digestion in the intestinal tract are ab... and reach the various tissues through the blood circulation ... main reaction by which hexoses are degraded is the anaerob...

Table 3 Intermediary reactions of lactic acid fermentation (glycolysis) in animal tissues (for formulae of intermediates see Figure ...)
These reactions occur in all animal tissues and in many micro organisms

No	Intermediary reactions			Enzyme catalysing the reaction*
1	glucose + adenosine triphosphate (ATP)	→	glucose 6-phosphate + adenosine diphosphate (ADP)	*Hexokinase*
2	glucose 6-phosphate	→	fructose 6-phosphate	Glucosephosphate isomerase
3	fructose 6-phosphate + ATP	→	fructose 1,6-diphosphate + ADP	Phosphofructokinase
4	fructose 1,6-diphosphate	→	dihydroxyacetone phosphate + 3-phosphoglyceraldehyde	Fructosediphosphate aldolase
5	dihydroxyacetone phosphate	→	3-phosphoglyceraldehyde	Triosephosphate isomerase
6	2 [3-phosphoglyceraldehyde + diphosphopyridine nucleotide (NAD) + phosphate	→	1,3-diphosphoglyceric acid + $NADH_2$]	Glyceraldehydephosphate dehydrogenase
7	2 [1,3-diphosphoglyceric acid + ADP	→	3-phosphoglyceric acid + ATP]	Phosphoglycerate kinase
8	2 [3-phosphoglyceric acid	→	2-phosphoglyceric acid]	Phosphoglycerate phosphom...
9	2 [2-phosphoglyceric acid	→	phosphopyruvic acid + H_2O]	Phosphopyruvate hydratase
10	2 [*phosphopyruvic acid* + ADP	→	*pyruvic acid* + ATP]	*Pyruvate kinase*
11	2 [pyruvic acid + $NADH_2$	→	lactic acid + NAD]	Lactate dehydrogenase
	Balance glucose + 2 ADP + 2 phosphate	→	2 lactic acid + 2 ATP + 2 H_2O	

* On enzyme nomenclature see page 382

Fig 1 The intermediates of glycolysis formed from glucose



D-Glucose (pyranose structure); D-Glucose 6 phosphate (a glucopyranose 6-phosphate); D-Fructose 6 phosphate (fructofuranose-6 phosphate); D-Fructose 1,6-diphosphate (furanose structure); D-Fructose 1,6-diphosphate (chain formula, indicating the fission to triose phosphate); Dihydroxyacetone phosphate + 3-phosphoglyceraldehyde; 1,3-Diphosphoglyceric acid; 3 Phosphoglyceric acid; 2 Phosphoglyceric acid; Phosphopyruvic acid; Pyruvic acid; Lactic acid

Table 4 Ancillary reactions of lactic acid fermentation in animal tissues

No.	Intermediary reactions			Enzyme catalysing the reactio
1	glycogen$_n$ + phosphate	⇌	glucose 1-phosphate + glycogen$_{n-1}$	α-Glucan phosphorylase
2	glucose 1-phosphate	⇌	glucose 6-phosphate	Phosphoglucomutase
3	fructose + ATP	→	fructose 6-phosphate + ADP	Hexokinase*
4	galactose + ATP	→	galactose 1-phosphate + ADP	Galactokinase[2]
5	galactose 1-phosphate + uridine diphosphoglucose	⇌	glucose 1-phosphate + uridine diphosphogalactose	Hexose 1-phosphate uridylyl-transferase[3]
6	uridine diphosphogalactose	⇌	uridine diphosphoglucose	UDPglucose epimerase[4]
7	uridine diphosphoglucose + pyrophosphate	⇌	uridine triphosphate (UTP) + glucose 1-phosphate	UDPG pyrophosphorylase[5]
8	fructose + ATP	→	fructose 1-phosphate + ADP	Ketohexokinase[6]
9	fructose 1-phosphate	⇌	dihydroxyacetone phosphate + glyceraldehyde	Ketose 1-phosphate aldolase[7]
10	D-glyceraldehyde + ATP	→	glyceraldehyde 3-phosphate + ADP	Triokinase[8]

* Hexokinase reacts similarly with many other hexoses, e.g., mannose, 2-deoxyglucose[1].

References

[1] Sols and Crane, *J. biol. Chem.*, 210, 581 (1954).
[2] Trucco et al., *Arch. Biochem.*, 18, 137 (1948).
[3] Kalckar et al., *Nature*, 172, 1038 (1953); Smith and Mills, *Biochim. biophys. Acta (Amst.)*, 13, 386 (1954).
[4] Leloir, L.F., *Arch. Biochem.*, 33, 186 (1951); Kalckar, H.M., *Advanc. Enzymol.*, 20, 111 (1958).
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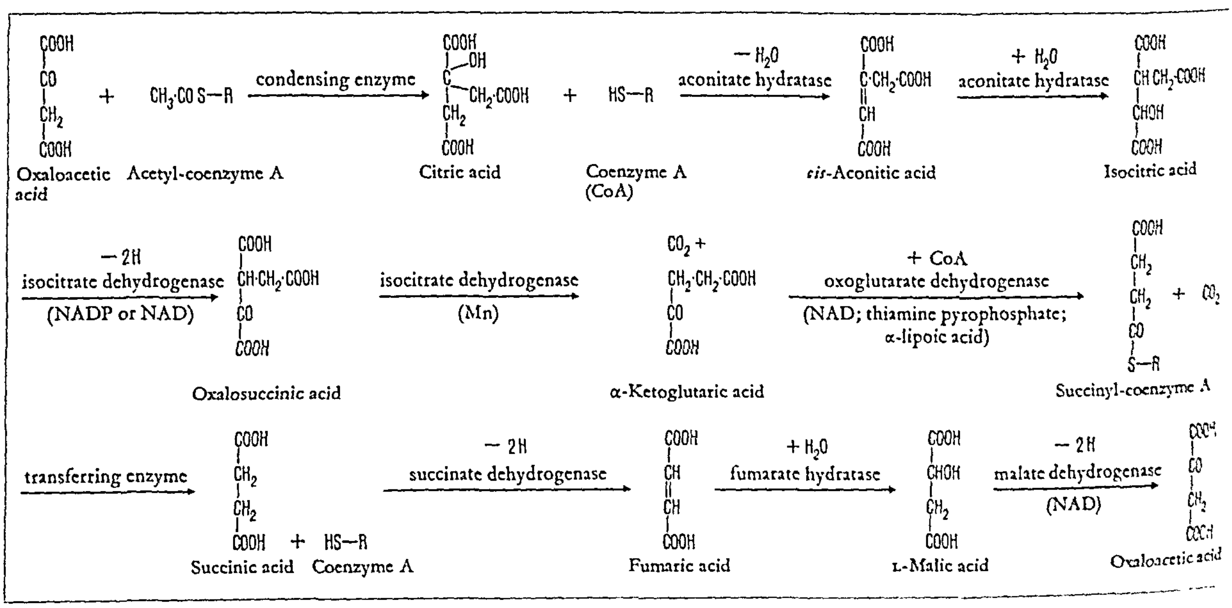
[6] Hers and Kusaka, *Biochim. biophys. Acta (Amst.)*, 11, 427 (1953); Park et al., *J. biol. Chem.*, 227, 231 (1957).
[7] Peanasky and Lardy, *J. biol. Chem.*, 233, 365 and 371 (1958).
[8] Bergmeyer et al., *Biochem. Z.*, 333, 471 (1961).

Fig. 2 The individual stages of the tricarboxylic acid cycle
The names of the enzymes are given above the arrows, those of the coenzymes required below the arrows.



Anaerobic lactic acid fermentation (glycolysis). The intermediary reactions of the lactic acid fermentation are given in Table 3. The changes of the carbon skeleton are summarized in Figure 1. The alcoholic fermentation of yeasts, moulds, other micro-organisms and plants follows essentially the same pathway except that reaction 11 (Table 3) is replaced by the following two reactions:

pyruvic acid → acetaldehyde + CO_2
acetaldehyde + $NADH_2$ → ethanol + NAD

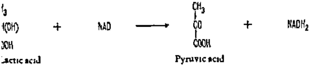
... of the alcoholic fermentation (reactions 1–10

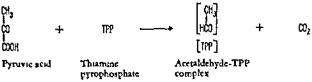
Reactions related to the lactic acid fermentation are shown in Table 4. Some of these reactions are concerned with the fermentation of other starting materials such as glycogen, fructose or galactose. When glycogen (or starch) is the starting material the balance reaction is

glycogen (1 glucose equivalent) + 3 ADP + 3 phosphate → 2 lactic acid + 3 ATP + 3 H_2O

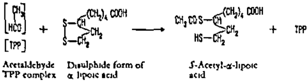
Oxidation of carbohydrate. As a rule, sugars are not oxidized as ... triose phosphate.

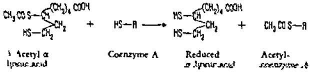
Lactic acid is first converted into acetyl-coenzyme A via pyruvic cid. The intermediary stages are assumed to be as follows:

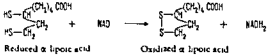




In the succeeding reaction the aldehyde-TPP complex reacts with







The sum of the last four reactions is

pyruvic acid + NAD + coenzyme A
→ acetyl-coenzyme A + $NADH_2$ + CO_2

Analogous reactions probably occur whenever α-ketonic acids are oxidized α-Ketonic acids arise in particular from α-amino acids, α-ketoglutarate is also formed during the tricarboxylic acid cycle

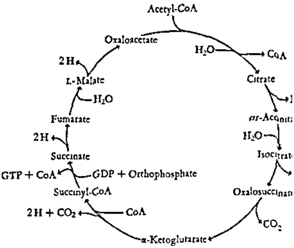
Acetyl-coenzyme A is oxidized to completion by the tricarboxylic acid cycle (also referred to in the literature as the 'citric acid cycle' or 'KREBS cycle') This cycle is initiated by a condensation of acetyl-coenzyme A and oxaloacetate leading to citrate Citrate undergoes a series of reactions that, on balance, are oxidative and in which other tricarboxylic acids and dicarboxylic acids arise They lead eventually to the regeneration of oxaloacetate, which thus becomes available for another turn of the cycle This means that oxaloacetate reacts after the manner of a catalyst The hydrogen atoms arising in the course of the cycle react ultimately with molecular oxygen to form water, and the overall effect of one turn of the cycle is therefore

$$CH_3COOH + 2O_2 \longrightarrow 2CO_2 + 2H_2O$$

The component reactions of the cycle are given in Figure 2. The cycle itself is shown diagrammatically in Figure 3

Fig 3 The tricarboxylic acid cycle

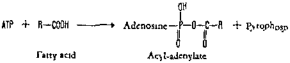
Substances entering the cycle (coenzyme A, H_2O) after the in condensation of 1 molecule of acetyl-coenzyme A and 1 molecu



Oxidative degradation of fat[1] (for references see page 393)

Fats are not oxidized in the ester form in which they are posited in tissues and present in foods Prior to oxidation f hydrolysed to free fatty acids and glycerol, a reaction catalyse lipases or other ester hydrolases

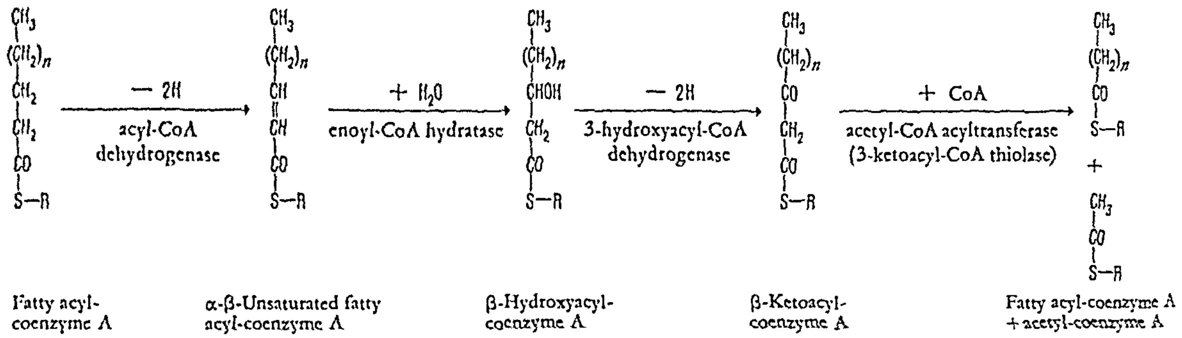
stages of the reaction have been identified The first leads to formation of an adenyl fatty acid (acyl-adenosine monop phate)[2]



The second is a transfer of the acyl group from adenylic aci coenzyme A:

Fig. 4 β-Oxidation of fatty acids

On enzyme nomenclature see page 382. Acyl-CoA-dehydrogenase is a flavoprotein, 3-hydroxyacyl-CoA-dehydrogenase requires NAD. All four reactions are reversible. The β-hydroxyacyl-coenzyme A compounds are optically active and belong to the L-series, *in contrast to the free β-hydroxybutyrate in blood and urine which belongs to the D-series. The latter arises by reduction of free acetoacetate*[4].



less than four carbon atoms. In the case of chains with even numbers of carbon atoms the last fragment is acetyl-coenzyme A, in the case of those with uneven numbers it is propionyl-coenzyme A.

The great majority of naturally occurring fatty acids contain an even number of carbon atoms and therefore yield acetyl-coenzyme A as the only product. The propionyl-coenzyme A formed from uneven chains is known to enter a CO_2-fixation reaction leading to succinic acid (see below).

The sequence of reactions by which fatty acids are oxidized has been referred to as the 'fatty-acid cycle'. It is not a cycle in the strict sense since the starting material is not regenerated by a full turn of the 'cycle'. What happens is a periodic repetition of the same *types* of reaction, but not of the same reactions. This is shown diagrammatically in Figure 5, from which it can be seen that the mechanism *is a 'spiral' rather than a 'cycle'*.

Carnitine (page 491) stimulates oxidation of fatty acids by promoting their transport from cytoplasm[13] to mitochondria through the formation of carnityl esters:

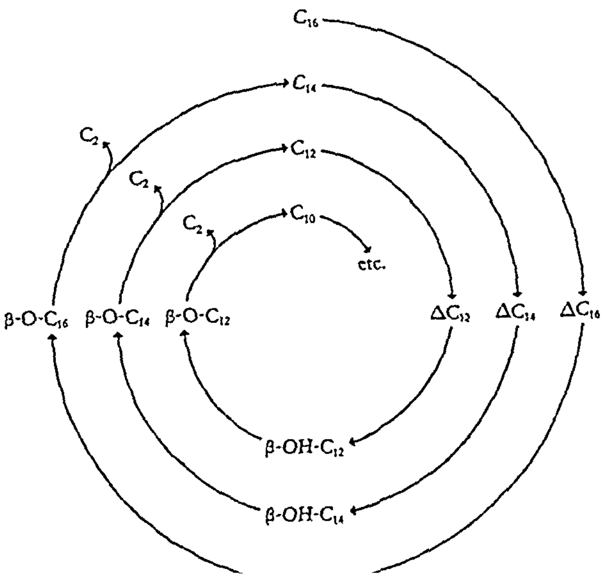
Acyl-CoA + carnitine ⇌ acylcarnitine + CoA

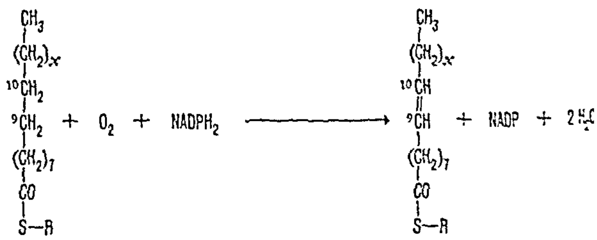
Unsaturated fatty acids are formed by desaturation of the coenzyme A esters of saturated fatty acids. This involves a coupled reaction in which both molecular oxygen and $NADPH_2$ are required[5]:

Fig. 5 Diagram of the 'spiral' of fatty-acid oxidation

C_{16}, C_{14}, etc.	= fatty acyl-coenzyme A
ΔC_{16}, ΔC_{14}, etc.	= unsaturated fatty acyl-coenzyme A
β-OH-C_{16}, β-OH-C_{14}, etc.	= β-hydroxyacyl-coenzyme A
β-O-C_{16}, β-O-C_{14}, etc.	= β-ketoacyl-coenzyme A
C_2	= acetyl-coenzyme A

The subscripts indicate the length of the carbon chain





Unsaturated fatty acids are also degraded by β-oxidation[13]. The double bond necessitates two additional enzymes, an isomerase that transposes it and converts it from cis to trans configuration, and an epimerase that converts the β-hydroxyacyl-coenzyme A formed by addition of H_2O to the bond from the D- to the L-configuration. *The latter is then degraded as shown in Figure 4.*

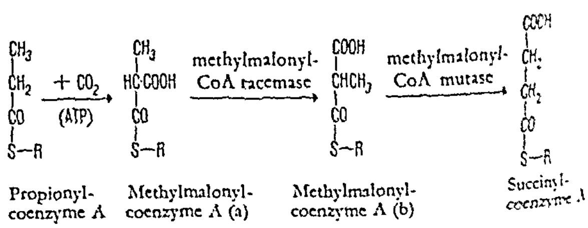
Glycerol, the second constituent of neutral fats, is converted in liver primarily to α-glycerophosphate:

glycerol + ATP → α-glycerophosphate + ADP

Alternatively, glycerol may be dehydrogenated to D-glyceraldehyde, which can yield glyceraldehyde 3-phosphate, or 2-phosphoglyceric acid via D-glycerate[6].

The triose phosphate formed from glycerol subsequently joins the reactions of triose phosphate arising from sugars.

Formation of succinic acid from propionyl-coenzyme A. As already mentioned, the propionyl-coenzyme A formed from fatty acids with uneven carbon chains yields succinic acid. This involves a CO_2-fixation reaction discovered by Ochoa et al.[7] followed by racemization and rearrangement of methylmalonyl-coenzyme A as follows[8]:



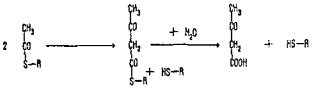
Hydrolysis of succinyl-coenzyme A then gives succinic acid.

Terminal oxidation of fat. The degradation reactions of fat so far considered bring about an incomplete oxidation of fatty acids and glycerol. The main product of this incomplete oxidation is acetic acid in the form of acetyl-coenzyme A. The only other product is succinic acid, which arises from the three terminal carbon atoms of the fatty-acid chain with odd numbers of carbon atoms. Since fatty acids with odd numbers of carbon atoms are uncommon in nature the total amount of succinate arising from fat is normally very small. Such fatty acids are uncommon because fatty-acid chains are usually synthesized from 2-carbon units.

Acetyl-coenzyme A and succinate are oxidized to completion by the reactions of the tricarboxylic acid cycle described on pages 390 and 391.

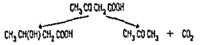
Ketosis. In ketosis due to starvation or diabetes or other causes, he 'ketone bodies', viz, acetoacetate ($CH_3 \cdot CO \cdot CH_2 \cdot COOH$),

zyme A condense in pairs to form acetoacetyl-coenzyme A which undergoes hydrolysis to free acetoacetate and coenzyme A (in liver free acetoacetate is not readily utilized):



Acetyl-coenzyme A — Acetoacetyl-coenzyme A — Acetoacetic acid

Acetoacetate is the primary ketone body β-Hydroxybutyrate is formed from it by reduction, acetone by decarboxylation The latter reaction is mainly nonenzymic, and is due to the inherent instability of acetoacetate:



β Hydroxybutyric acid — Acetone

It follows that all substances which can form acetyl-coenzyme A,

Ancillary reactions of fatty acid degradation Some ancillary degradation reactions of fatty acids are the following

(*a*) Acetoacetyl-CoA-hydrolase liberates free acetoacetate from the coenzyme A derivative

acetoacetyl-coenzyme A + H_2O
→ acetoacetate + coenzyme A

This reaction is assumed to play a role in the appearance of the ketone bodies in blood and tissues in ketosis[10]

(*b*) 3-Hydroxybutyrate dehydrogenase catalyses the reversible interconversion of acetoacetate and β-hydroxybutyrate

β-hydroxybutyrate + NAD ⇌ acetoacetate + $NADH_2$

and is responsible for the formation and removal of β-hydroxybutyrate

(*c*) An enzyme transferring coenzyme A reversibly between acetoacetate and succinate (3 ketoacid CoA-transferase) may initiate the breakdown of free acetoacetate

acetoacetate + succinyl-coenzyme A
⇌ acetoacetyl-coenzyme A + succinate[11]

(*d*) Acetoacetate breakdown can also be initiated by the reaction

acetoacetate + coenzyme A + ATP
→ acetoacetyl-coenzyme A + AMP + pyrophosphate[12]

This is analogous to the reaction initiating the degradation of fatty acids (page 391) and may involve the same type of intermediary stages, i e, the formation of acetoacetyl-adenylate

References

[9] Krebs, H A, *Arch intern Med*, 107, 51 (1961), Wieland and Löffler,

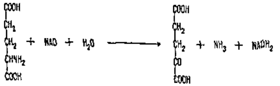
Intermediary stages of the degradation of amino acids

General degradation reactions Some degradation reactions are common to all or several amino acids. These are (*a*) oxidative deamination, (*b*) transamination, (*c*) nonoxidative decarboxylation

Oxidative deamination The general reaction scheme of oxidative deamination is as follows

α Amino acid — α Ketonic acid

Liver and kidney contain enzymes that



L-Glutamic acid — α Ketoglutaric acid

This enzyme differs from all the other enzymes

Transamination. Transamination is a reversible reaction between amino and α-ketonic acids leading to the exchange of the amino and ketonic groups An example is the following:

Table 5 Some transamination reactions in animal tissues[1]

Reactions			Remarks
α-ketoglutarate + L-α-amino acid	⇌	L-glutamate + α-ketonic acid	Most α-amino acids can react in this way in liver and many other tissues
α-ketoglutarate + L-ornithine	⇌	L-glutamate + L-glutamic γ-semialdehyde	Involves transfer of ω-amino groups; occurs in liver[2,3]
glyoxylate + L-ornithine	⇌	glycine + L-glutamic γ-semialdehyde	
pyruvate + L-ornithine	⇌	L-alanine + L-glutamic γ-semialdehyde	
L-glutamine + α-keto-γ-guanidinovaleric acid	⇌	α-ketoglutarate + L-arginine + NH_3	Occurs in liver[2]
L-alanine + hydroxypyruvate	⇌	pyruvate + L-serine	Occurs in liver and kidney[4]
α-ketoglutarate + γ-aminobutyrate	⇌	L-glutamate + succinic semialdehyde	Occurs in brain and liver[5]
α-ketoglutarate + β-alanine	⇌	L-glutamate + malonic semialdehyde	Occurs in brain and liver[6]

References

[1] For reviews see COHEN and SALLACH, in GREENBERG, D.M. (Ed.), *Metabolic Pathways*, vol. 2, Academic Press, New York, 1961, page 1; KREBS, H.A., in MUNRO and ALLISON (Eds.), *Mammalian Protein Metabolism*, vol. 1, Academic Press, New York, 1964, page 125; GUIRARD and SNELL, in FLORKIN and STOTZ (Eds.), *Comprehensive Biochemistry*, vol. 15, Elsevier, Amsterdam, 1964, page 138.

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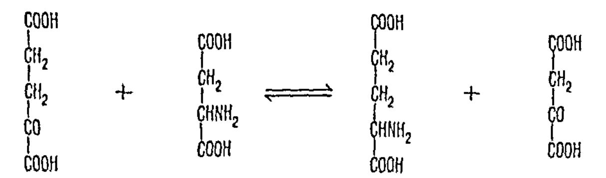


α-Ketoglutaric acid   L-Aspartic acid   L-Glutamic acid   Oxaloacetic acid

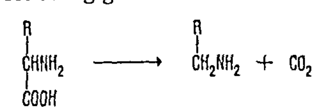
The majority of α-amino acids can replace aspartic acid in this type of reaction, according to the general scheme

α-ketoglutarate + α-amino acid
⇌ L-glutamate + α-ketonic acid

but the rate of reaction is by far the highest when aspartic acid is the amino group donor. Transaminases occur in most animal tissues as well as in micro-organisms and plants. Several tissues contain special types of transaminases. Some of these tissues are listed in Table 5.

Transaminases readily diffuse from tissues into the blood plasma when the tissue has suffered damage. This is the basis of a clinical test, the rise of the plasma level of transaminase in cardiac infarction. Pyridoxal phosphate is a prosthetic group of transaminases.

Decarboxylation. Decarboxylation of amino acids proceeds according to the following general scheme:



α-Amino acid   Primary amine

Decarboxylases occur in animal tissues and in many micro-organisms, but not every amino acid can undergo decarboxylation. Reactions that have been recorded are listed in Table 6. The significance of some of the decarboxylations occurring in animal tissues lies in the supply of essential metabolites, e.g., of taurine (required for the synthesis of bile acids), of histamine and serotonin (required for the functional activities of nervous tissue) or of ethanolamine (required for the synthesis of cephalins, choline and acetylcholine). Pyridoxal phosphate (see page 474) is a coenzyme also in most decarboxylation reactions. A notable exception is the decarboxylation of histidine.

Table 6 Decarboxylation of L-amino acids[1]
Most of the bacterial reactions listed below occur in the micro-organisms of the intestinal tract, e.g., *Escherichia coli, Streptococcus faecalis, Clostridium* species

Amino acid	Amine formed	Occurrence of enzyme
Histidine	Histamine	Animal tissues, bacteria
Cysteic acid	Taurine	Liver
Glutamic acid	γ-Aminobutyric acid	Brain, bacteria
5-Hydroxytryptophan	5-Hydroxytryptamine (serotonin)	Animal tissues
3,4-Dihydroxyphenylalanine	3,4-Dihydroxyphenylethylamine	Animal tissues
Serine	Ethanolamine	Animal tissues[2]
Lysine	Cadaverine	Bacteria
Ornithine	Putrescine	Bacteria
Tyrosine	Tyramine	Bacteria
Phenylalanine	Phenylethylamine	Bacteria
Aspartic acid	β-Alanine	Bacteria
α,ε-Diaminopimelic acid	Lysine	Bacteria[3]

References

[1] For reviews see GUIRARD and SNELL, in FLORKIN and STOTZ (Eds.), *Comprehensive Biochemistry*, vol. 15, Elsevier, Amsterdam, 1964, page 138; KREBS, H.A., in MUNRO and ALLISON (Eds.), *Mammalian Protein Metabolism*, vol. 1, Academic Press, New York, 1964, page 125.

[2] ARNSTEIN, H.R.V., *Biochem. J.*, 48, 27 (1951).

[3] DEWEY and WORK, *Nature*, 169, 533 (1952).

Degradation of individual amino acids[1]

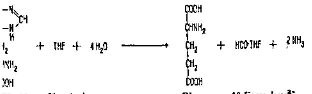
(for references see page 399)

L-Glutamic acid, L-aspartic acid, L-alanine. On oxidative deamination or transamination these three amino acids yield α-ketonic acids which also occur as intermediates in the metabolism of carbohydrate; they are α-ketoglutarate, oxaloacetate and pyruvate respectively.

The degradation of the six amino acids *L-histidine, L-arginine, L-citrulline, L-ornithine, L-proline and L-hydroxyproline* leads in every case to glutamic acid and thence to α-ketoglutarate.

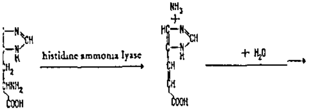
L-Histidine is converted to glutamic acid by an enzyme complex of liver tissue that includes tetrahydrofolic acid (THF) as a co-factor. The overall result of the action of this complex is an hydrolysis according to the following scheme:

(For references see page 399)

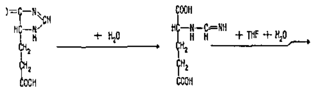


Histidine Tetrahydrofolic acid L-Glutamic acid 10-Formyltetrahydrofolic acid

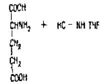
Six intermediate stages have been identified[2], of which the first the fission to ammonia and an unsaturated derivative of histidine.



Histidine Urocanic acid



Imidazolonepropionic acid Formiminoglutamic acid



L-Glutamic acid Formiminotetrahydrofolic acid

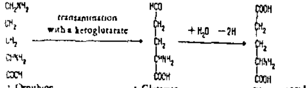
Formimino-THF is converted into 5,10-methylidyne-THF and 10-formyl-THF. For these and further reactions see pages 436 and 437.

Oxidative deamination or transamination of histidine yields imidazolepyruvic acid[3], which may be further converted into imidazolelactic acid and imidazoleacetic acid.

A similar pathway of histidine degradation to glutamic acid has been shown in bacteria, although tetrahydrofolic acid does not appear to be involved.

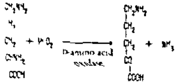
L-*Citrulline* and L-*arginine* are converted in liver tissue into ornithine by the reactions of the ornithine cycle (see pages 442 and 443).

L-*Ornithine* is known to yield glutamic γ-semialdehyde by transamination (see page 394) and the semialdehyde can form glutamic acid by dehydrogenation.



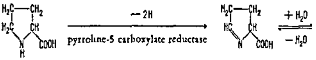
L-Ornithine L-Glutamic γ-semialdehyde L-Glutamic acid

D-*Ornithine*, under the influence of D-amino-acid oxidase, follows a different route, the primary step being the removal of the α-amino group.

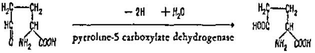


D-Ornithine α-Keto-δ-aminovaleric acid

L-*Proline* forms glutamic acid by the following three steps[4], which include two dehydrogenations:



L-Proline L-Δ^1-Pyrroline-5-carboxylic acid



L-Glutamic γ-semialdehyde L-Glutamic acid

These reactions have been shown to occur in both liver and bacteria.

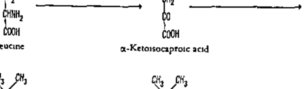
D-*Proline* reacts differently in mammalian liver or kidney and gives the same α-ketonic acid as D-ornithine. This is to be expected as the point of attack of D-amino-acid oxidase is always the α-carbon atom.

L-*Hydroxyproline*. γ-Hydroxyglutamic acid can be formed from [illegible]

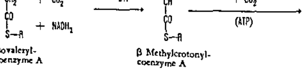
The degradation of the *leucines* and *valines* follows initially a com- [illegible]

coenzyme A and propionyl-coenzyme A. As already mentioned (page 392), propionyl-coenzyme A eventually yields succinate.

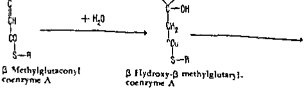
Leucine yields three molecules of acetyl-coenzyme A. The intermediate stages are as follows[6]:



Leucine α-Ketoisocaproic acid

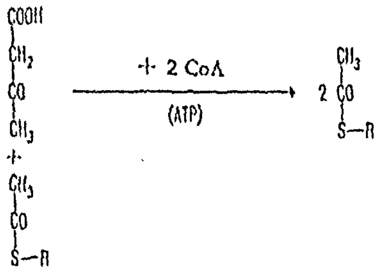


Isovaleryl-coenzyme A β-Methylcrotonyl-coenzyme A



β-Methylglutaconyl coenzyme A β-Hydroxy-β-methylglutaryl-coenzyme A

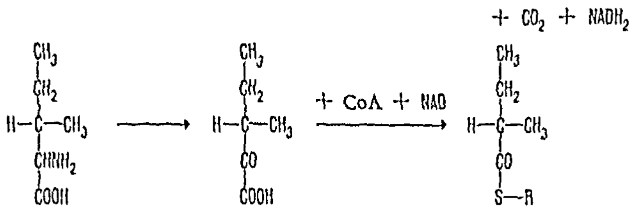
(For references see page 399)



Acetoacetic acid + acetyl-coenzyme A

Acetyl-coenzyme A (2 molecules)

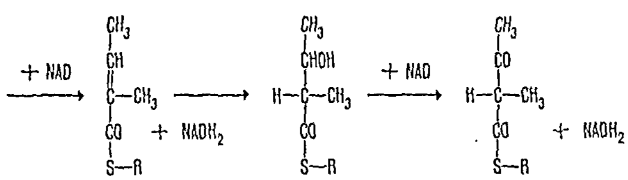
Isoleucine yields one molecule of acetyl-coenzyme A and one molecule of propionyl-coenzyme A[7]:



Isoleucine

α-Keto-β-methyl-valeric acid

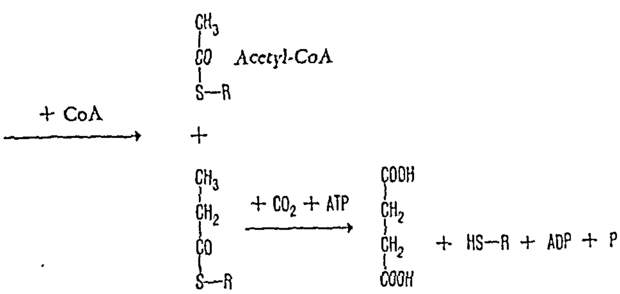
α-Methylbutyryl-coenzyme A



Tiglyl-coenzyme A

α-Methyl-β-hydroxybutyryl-coenzyme A

α-Methylacetoacetyl-coenzyme A

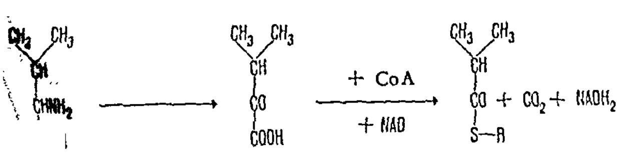


Propionyl-coenzyme A

Succinic acid

The mechanism of the last of these reactions is discussed on page 392.

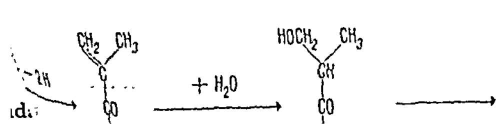
Valine is degraded by analogous reactions to the stage of β-hydroxyisobutyryl-coenzyme A. This compound is hydrolysed by a thiol ester hydrolase to yield β-hydroxyisobutyric acid, which is further metabolized as shown below[8]:

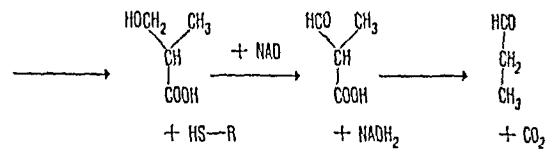


ıe

α-Ketoisovaleric acid

Isobutyryl-coenzyme A

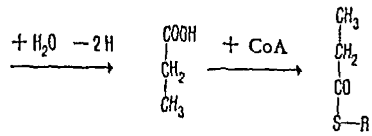




β-Hydroxyisobutyric acid + coenzyme A

Methylmalonyl semialdehyde

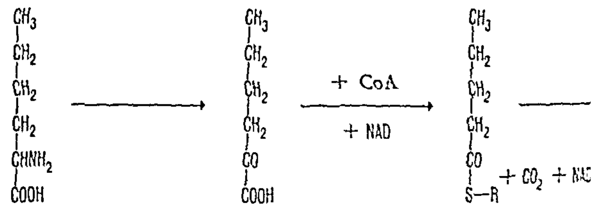
Propionic aldehyde



Propionic acid

Propionyl-coenzyme A

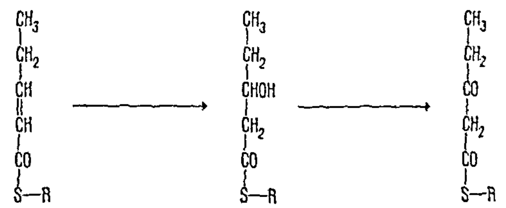
Norleucine (which is not a protein constituent) has not bε studied in detail, but by analogy it is expected to undergo t following sequence of reactions leading to propionyl-coenzyme and acetyl-coenzyme A:



Norleucine

α-Ketocaproic acid

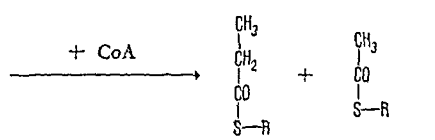
Valeryl-coenzyme A



β-Ethylacrylyl-coenzyme A

β-Hydroxyvaleryl-coenzyme A

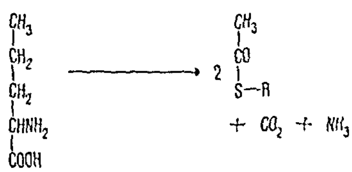
β-Ketovaleryl-coenzyme A



Propionyl-coenzyme A

Acetyl-coenzyme A

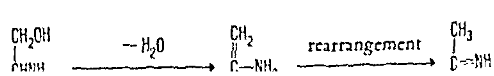
Norvaline, by the same types of reaction, forms two molecules of acetyl-coenzyme A:



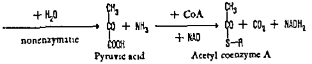
α-*Aminobutyric acid* by analogy forms propionyl-coenzyme A and thence succinate.

The *hydroxyamino acids* (serine, homoserine, threonine) and *glycine* react atypically in that the oxidative deamination is not the primary step.

Serine yields anaerobically ammonia and pyruvic acid in animal tissues as well as in micro-organisms. The intermediate steps are assumed to be as follows[9]:

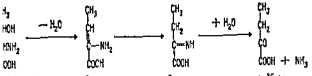


(For references see page 399)

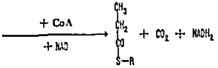


Pyruvic acid   Acetyl coenzyme A

L-*Threonine* (an intermediate in the metabolism of methionine) is nown to undergo an analogous nonoxidative deamination on ncubation with liver extracts, yielding α-ketobutyric acid and mmonia[10]:

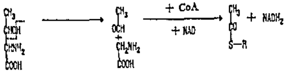


L-Threonine   α-Amino-crotonic acid   α-Imino-butyric acid   α-Keto-butyric acid



Propionyl-coenzyme A

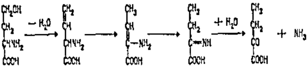
It may also be split by an aldolase to give acetaldehyde and glycine[11]



L-Threonine   Acetaldehyde + glycine   Acetyl-coenzyme A

The acetaldehyde formed can be converted into acetyl-coenzyme A, whilst the glycine reacts as described later

Homoserine (an intermediate in the metabolism of methionine) yields α-ketobutyric acid and ammonia by a nonoxidative deamination analogous to that of serine[12]

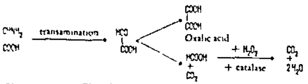


Homoserine   α-Amino-vinylacetic acid   α-Amino-crotonic acid   α-Imino-butyric acid   α-Ketobutyric acid

Glycine The pathway of degradation of glycine is not yet fully clarified One route is the conversion into serine by an aldol condensation with hydroxymethyltetrahydrofolic acid[13]

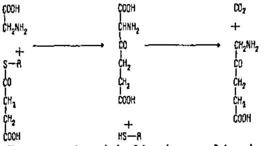
Glycine   Hydroxymethyltetra-hydrofolic acid   L-Serine   Tetrahydro folic acid

[illegible] monly occurring in animal tissues

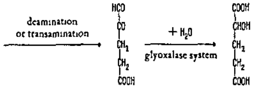


Glycine   Glyoxylic acid   Oxalic acid   Formic acid

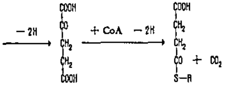
Another possible pathway of glycine degradation is initiated by the condensation with succinyl-coenzyme A[15]:



Glycine + succinyl-coenzyme A   α-Amino-β ketoadipic acid + coenzyme A   δ-Aminolaevulinic acid



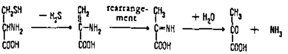
α-Ketoglutaric semialdehyde   α-Hydroxy-glutaric acid



α-Keto-glutaric acid   Succinyl-coenzyme A

The reactions up to the stage of δ aminolaevulinic acid have been firmly established but the pathway beyond δ-aminolaevulinic acid leading eventually to succinyl-coenzyme A is hypothetical and based on analogies.

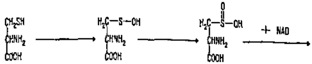
L-*Cysteine* can be desulphurated, under the influence of the enzyme cysteine desulphhydrase, to yield pyruvate, NH_4 and H_2S[16] The intermediate stages have been formulated as follows



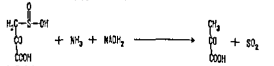
L-Cysteine   α-Aminoacrylic acid   α-Iminopropionic acid   Pyruvic acid

These reactions are closely analogous to those of serine

A more important metabolic route involves oxidation at the sulphur atom



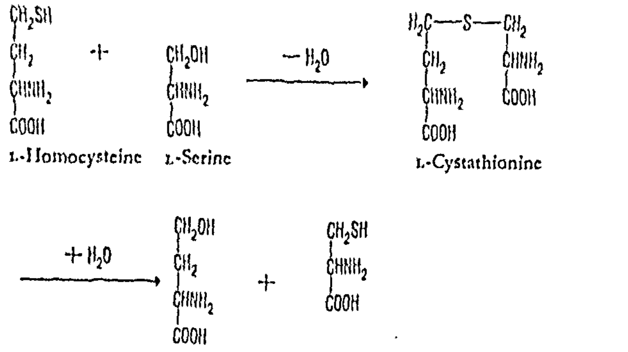
L Cysteine   Cysteinesulphenic acid (hypothetical)   Cysteinesulphinic acid



β Sulphinyl-pyruvic acid   Pyruvic acid

Cystine is converted in liver tissue into the same products as cysteine, it is assumed that it undergoes reduction to cysteine before it is degraded

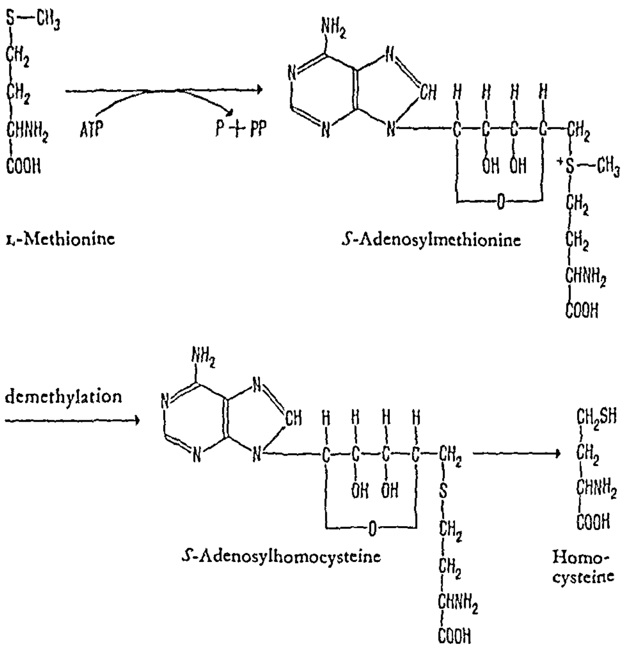
L-*Homocysteine*, an intermediate in methionine oxidation, undergoes a transsulphuration reaction with cystathionine as intermediate[17]. In this way the methionine sulphur becomes that of cysteine, the pathway of degradation of which is shown above



L-Homocysteine L-Serine L-Cystathionine

L-Homoserine L-Cysteine

L-*Methionine* is first converted to an active form, a step requiring adenosine triphosphate (ATP)[18]. The product, *S*-adenosylmethionine, is a methyl group donor (in choline synthesis).

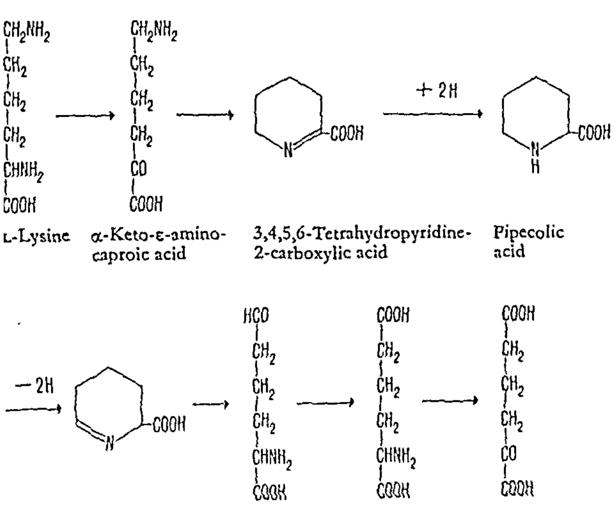


L-Methionine *S*-Adenosylmethionine

S-Adenosylhomocysteine Homocysteine

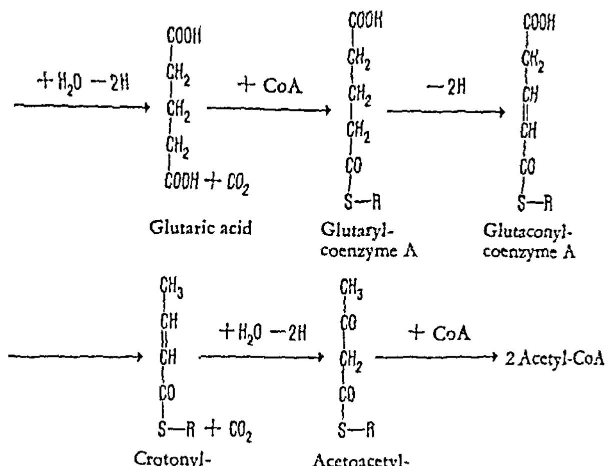
The fate of homocysteine has already been discussed.

L-*Lysine*. The following pathway of the degradation of lysine is essentially based on isotopic evidence and the isolation of most of the intermediates[19]:



L-Lysine α-Keto-ε-amino-caproic acid 3,4,5,6-Tetrahydropyridine-2-carboxylic acid Pipecolic acid

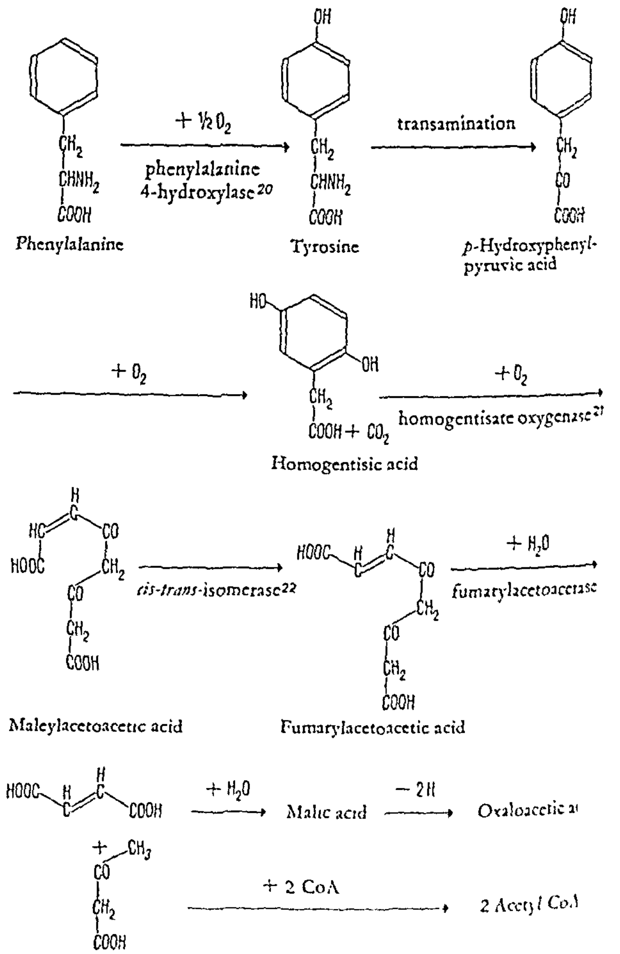
2,3,4,5-Tetra- α-Amino- α-Amino- α-Keto- adipic acid



Glutaric acid Glutaryl-coenzyme A Glutaconyl-coenzyme A

Crotonyl-coenzyme A Acetoacetyl-coenzyme A

Phenylalanine and *tyrosine* are degraded in animal tissues by the reactions shown in the following scheme. Several unusual enzymes are involved. The end-products as formulated are oxaloacetic acid and acetyl-coenzyme A:



Phenylalanine Tyrosine *p*-Hydroxyphenylpyruvic acid

Homogentisic acid

Maleylacetoacetic acid Fumarylacetoacetic acid

Fumaric acid + acetoacetic acid

On inborn errors of phenylalanine and tyrosine metabolism se pages 448–449.

Tryptophan is incompletely burned in man and in most animals Products of incomplete oxidation appearing in the urine are indole 3-acetic acid, anthranilic acid, kynurenine, hydroxykynurenine kynurenic acid and 8-hydroxykynurenic ('xanthurenic') acid. Tryptophan and 3-hydroxyanthranilic acid (but not anthranilic acid can be converted into nicotinic acid in some animals, though only

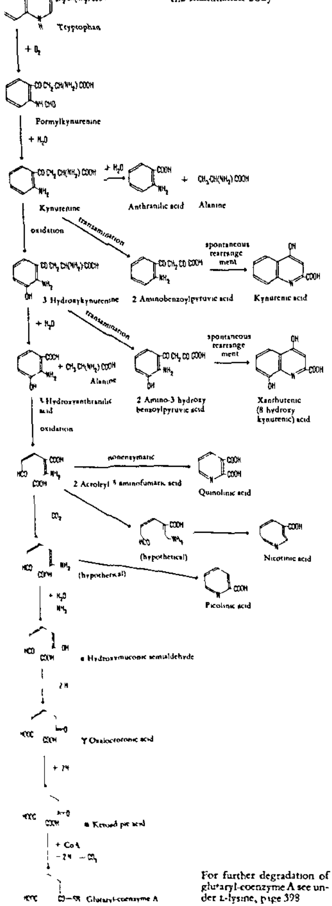


Fig 6 Degradation of tryptophan in the mammalian body[23]

For further degradation of glutaryl-coenzyme A see under L-lysine, page 398

products is given in Figure 6

References

[1] For reviews see GREENBERG, D M (Ed), *Metabolic Pathways*, vol 2, Academic Press, New York, 1961, KREBS, H A , in MUNRO and ALLISON (Eds) *Mammalian Protein Metabolism*, vol 1, Academic Press, New York, 1964 page 125

[6] BACHHAWAT et al , *J biol Chem* , 216, 727 (1955), 219, 539 (1956), DE CAMPILLO-CAMPBELL et al , *Biochim biophys Acta (Amst)*, 31, 290 (1959)

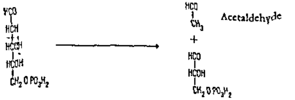
[7] COON et al , *J biol Chem* , 199, 75 (1954), ROBINSON et al , *J biol Chem* , 218 391 (1956)

Degradation of food constituents other than carbohydrate, fat and protein (for references see page 401)

Foods contain a number of

Pentoses, reacting in the form of ribose 5-phosphate, can be converted to glucose 6-phosphate and triose phosphate by reactions of the pentose phosphate cycle [reactions (3) to (8) of Table page 422] Three molecules of ribose 5-phosphate form two molecules of glucose 6 phosphate and one molecule of glyceraldehyde phosphate

2-Deoxyribose 5-phosphate can be split by aldolase to acetaldehyde and glyceraldehyde phosphate[1]

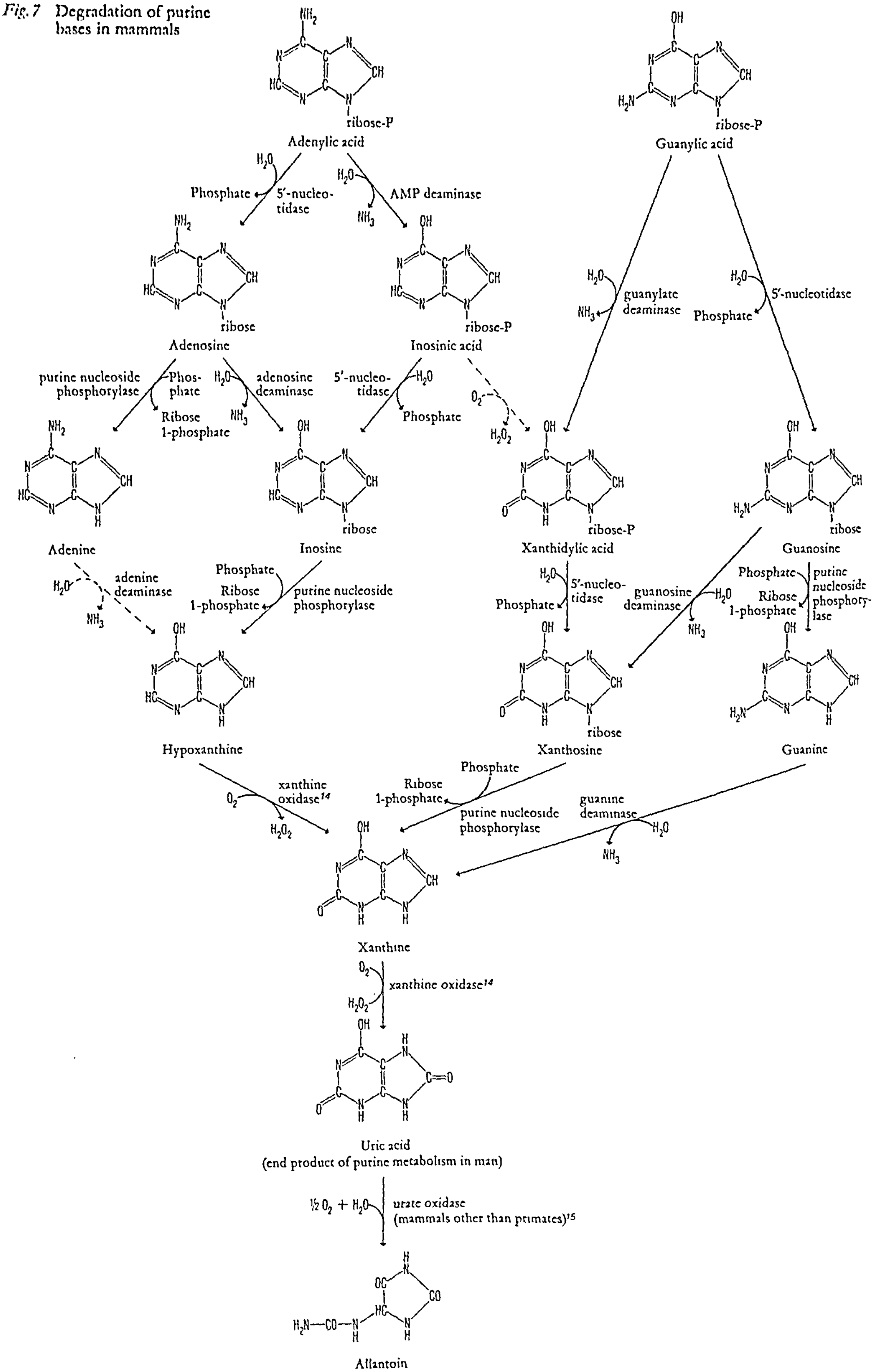


2 Deoxyribose 5-phosphate — Glyceraldehyde 3 phosphate

The acetaldehyde can be converted into acetyl-coenzyme A.

(continued on page 4

Fig. 7 Degradation of purine bases in mammals



(continued from page 399)

Degradation of purine bases in man and mammals[12]. The degradation

pathways depending on whether deamination and oxidation precede or do not precede the fission of the nucleotide or nucleoside The end-product of purine degradation is the same, irrespective of the route. It is uric acid in man and other primates, and allantoin

relatively slow by broken arrows

Purine deaminases. Three types of enzyme are known – adenine deaminase, adenosine deaminase and AMP deaminase – that hydrolyse adenine, adenosine and AMP respectively to yield ammonia and the corresponding derivative of hypoxanthine. Of these, the occurrence of adenine deaminase in mammals is uncertain. Adenosine deaminase occurs in most tissues of higher animals AMP deaminase occurs abundantly in striated muscle but is relatively weak in other tissues, including heart muscle[13].

Three types of enzyme are known – guanine deaminase, guanosine deaminase, and guanylate deaminase – that hydrolyse guanine,

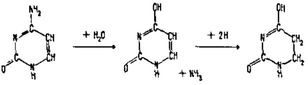
Purine oxidases The oxidation of purines can occur at the ribotide level or at the free base level The oxidation of inosinic acid

and in many tissues[14]

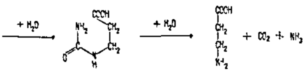
Urate oxidase oxidizes uric acid to allantoin[15] It occurs in liver and kidney of mammals other than man and primates

Nucleotidases and purine nucleoside phosphorylases The fission of nucleotides is hydrolytic, the products being nucleosides and inorganic phosphate The fission of nucleosides in animals is phosphorolytic, the products being a purine base and ribose 1-phosphate Micro-organisms also contain nucleoside hydrolases, but these have not so far been demonstrated in higher animals

Degradation of pyrimidines Cytosine and uracil are converted into β alanine by the liver through the following reaction sequence[9]

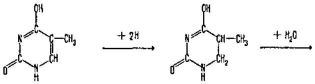


Cytosine Uracil Dihydrouracil

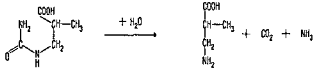


Carbamyl β alanine β Alanine

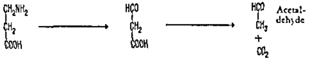
Thymine, by analogous reactions[10], forms α methyl-β alanine in liver Other pathways occur in bacteria[11]



Thymine Dihydrothymine



Carbamyl β-aminoisobutyric acid (α methylcarbamyl β alanine) β Aminoisobutyric acid (α-methyl-β-alanine)



β Alanine Malonic semialdehyde Acetaldehyde

α-Methyl-β-alanine reacts in an analogous manner to give methylmalonic semialdehyde[4], which can form propionaldehyde and subsequently succinic acid via propionyl-coenzyme A

About 5–10% of humans excrete α-methyl-β-alanine in the urine in quantities up to 300 mg daily[5] This is assumed to be an inborn error of metabolism It is probably due to an abnormality in the enzymes responsible for the degradation of α-methyl-β-alanine[6]

In *cholesterol*, only the side chain undergoes complete oxidation. A specific enzyme can cleave off the side chain, forming isocaproic acid and leaving the ring system in the form of pregnenolone[7] Isocaproic acid in turn is broken down to propionic acid and acetyl-coenzyme A[8] The ring system of cholesterol and the steroids is not oxidized to CO_2[7]

Other cell constituents that are essentially not oxidized in the body to CO_2 are the *iron porphyrins* (see pages 359 sq) derived from haemoglobin and cytochromes (these are excreted in the form of bile pigments and their derivatives, see page 362), and the *uronic acids* (see page 323) contained in mucins, in hyaluronic acid and in the chondroitin sulphate of cartilage and tendons

References

[1] Racker, E, *J biol Chem*, 196, 347 (1952)

Degradation of the principal foodstuffs

consisting of several hexoses, glycerol, about twenty amino acids and a number of fatty acids – is incompletely burned. The products listed in Table 7, apart from carbon dioxide and water, are either acetic acid in the form of acetyl-coenzyme A or an intermediate of the tricarboxylic acid cycle, α-ketoglutarate, succinate, fumarate or oxaloacetate. Acetic acid constitutes the main product: two-thirds of the carbon of carbohydrate and glycerol, all the carbon of the common fatty acids and about half the carbon skeleton of amino acids yield acetyl-coenzyme A. α-Ketoglutarate arises from glutamic acid, histidine, arginine, citrulline, ornithine, proline and hydroxyproline; oxaloacetate from aspartate; fumarate from part of the benzene ring of tyrosine and phenylalanine; succinate from threonine, isoleucine, valine, methionine, α-aminobutyric acid, propionic acid and the three terminal carbon atoms of fatty acids with an odd number of carbon atoms.

The products of the first stage of the oxidative breakdown are completely oxidized in the second stage, the tricarboxylic acid cycle, which thus represents a common terminal pathway of oxidation shared by all foodstuffs. Almost two-thirds of the total energy released in the combustion of foodstuffs appears during the reactions of this cycle.

Any surplus oxaloacetate not required as a catalyst in the cycle can be decarboxylated to pyruvate, whence it is converted into acetyl-coenzyme A and undergoes complete oxidation.

Table 7 Survey of the products formed by the initial oxidative degradation reactions of the basic constituents of foodstuffs

These reactions all lead to acetyl-coenzyme A and/or the intermediates of the tricarboxylic acid cycle.

Starting material	Products of initial reactions (CO_2 omitted)
Glucose, other hexoses	2 acetyl-coenzyme A
Fatty acids (even-numbered chains of *n* C-atoms)	½ *n* acetyl-coenzyme A
Fatty acids (odd-numbered chains of *n* C-atoms)	½ (*n*−3) acetyl-coenzyme A 1 succinate (via propionyl-coenzyme A)
Glycerol, alanine, cysteine, cystine, serine	1 acetyl-coenzyme A
Glutamic acid, histidine, arginine, ornithine, citrulline, proline, hydroxyproline	1 α-ketoglutarate
Aspartic acid	1 oxaloacetate
Leucine	3 acetyl-coenzyme A
Isoleucine	1 acetyl-coenzyme A 1 succinate (via propionyl-coenzyme A)
Valine	1 succinate (via methyl-malonic semialdehyde
Norleucine	1 acetyl-coenzyme A
Norvaline	2 acetyl-coenzyme A 1 succinate (via propionyl-coenzyme A)
α-Aminobutyric acid, homoserine, homocysteine, methionine	1 succinate (via propionyl-coenzyme A)
Glycine*	1 acetyl-coenzyme A (via serine)
Threonine	1 succinate
Lysine	2 acetyl-coenzyme A
Phenylalanine, tyrosine	1 fumarate 2 acetyl-coenzyme A
Tryptophan	at most 3 acetyl-coenzyme A**

* Glycine may also be oxidized by a special cycle (see page 397).
** Other products are formed that are not oxidizable (see page 398).

In so far as substances other than carbohydrate, fat and am[ino] acids can supply energy, their degradation follows pathways whi[ch] like those of carbohydrate, fat and amino acids, yield acetyl-co[en]zyme A and/or an intermediate of the tricarboxylic acid cycle.

Mechanism of biological oxidations
(for references see page 404)

General. The degradation reactions discussed so far take pl[ace] when the foodstuff molecules are 'burned' by molecular oxyg[en]. This 'combustion' is not, however, a direct reaction of molecul[ar] oxygen with the substrate but a transference of electrons, mediat[ed] by several complex enzyme systems, in which oxygen is the ul[ti]mate electron acceptor. In order to understand the action of the[se] catalysts, it has to be borne in mind that biological oxidatio[ns] include three types of reaction that at first sight appear to [be] different but are basically the same. The three types are illustrat[ed] by the following cases:

Case 1. Addition of oxygen atoms, for example:

$$CH_3\cdot CHO \xrightarrow{+O} CH_3\cdot COOH$$

Acetaldehyde — Acetic acid

Case 2. Removal of hydrogen atoms, for example:

$$CH_3\cdot CHOH\cdot COOH \xrightarrow{-2H} CH_3\cdot CO\cdot COOH$$

Lactic acid — Pyruvic acid

Case 3. Transformation of a metal from a lower to a higher va[lency] state by removal of electrons, for example:

$$Fe^{++} \rightarrow Fe^{+++} + e^-$$

All three cases are seen to be basically similar – as removal o[f] H atoms – if the participation of water is also considered:

Case 1 may then be formulated as

$$CH_3\cdot CHO + H_2O \rightarrow CH_3\cdot CH(OH)_2 \xrightarrow{-2H} CH_3\cdot COOH$$

Acetaldehyde — Hydrated form of acetaldehyde — Acetic acid

and case 3 as

$$2\,Fe^{++} + 2\,H_2O \xrightarrow{-2H} 2\,Fe^{+++} + 2\,OH^-$$

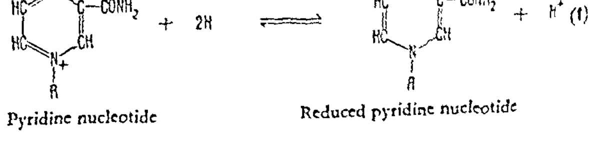
The common feature of all types of biological oxidations is a removal of electrons, although this is often either written as a removal of H (i.e., electron and proton) or as the addition of O atoms. There are instances in which neither H nor O atoms are directly involved, as in the oxidation of one heavy metal catalyst by another:

$$R\cdot Fe^{++} + R'\cdot Fe^{+++} \rightarrow R\cdot Fe^{+++} + R'\cdot Fe^{++}$$

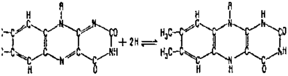
Such reactions occur in living cells between iron porphyrins (cytochromes) in which the electrons travel more or less directly from one iron atom to another. Because there are cases where electron transfer is the only change, the formulation of oxidation as electron transport is looked upon as the most general and fundamental description of this process.

Biological oxidations may therefore be described in terms of the transfer of electrons, and the reactions whereby electrons are transferred from substrates to molecular oxygen are usually referred to as electron transport reactions.

The catalysts of biological oxidations[1,2]. Three major types of catalysts participate in biological oxidations. They are enzymes which have as prosthetic groups respectively pyridine nucleotides, flavin nucleotides and iron porphyrins. The prosthetic groups undergo reversible oxidation and reduction. The catalysts thus exist in (at least) two forms, oxidized and reduced. The mechanism of reduction is illustrated by reaction (1) for a pyridine nucleotide, and by reaction (2) for a flavin nucleotide:



Pyridine nucleotide — Reduced pyridine nucleotide

 (2)

Flavin nucleotide   Reduced flavin nucleotide

These reactions are written as similar to case 2 above The iron ...oms of iron porphyrin enzymes are reversibly oxidized and re...iced as described in case 3 above.

Catalyst	E'_0 (volts)
Oxygen electrode ($H_2O \rightleftharpoons \frac{1}{2}O_2 + 2H + 2e^-$)	+ 0 81
Cytochrome c	+ 0 25[3]
Flavin nucleotides (free)......	− 0 20[3]
Pyridine nucleotides (free)......	− 0 32[3]
Hydrogen electrode ($H_2 \rightleftharpoons 2H^+ + 2e^-$)	− 0 42

As seen from this table, the potentials of the electron carriers are ...uch that the reduced form of pyridine nucleotides can act as re...ductant of the flavin nucleotides which, in turn, can act as reduc...ant of the oxidized cytochromes The order in which the catalysts ...ransport electrons from the substrate to molecular oxygen may ...herefore be expressed in the following series of reactions·

Substrate + pyridine nucleotide → oxidized substrate + reduced pyridine nucleotide (a)

Reduced pyridine nucleotide + flavin nucleotide → pyridine nucleotide + reduced flavin nucleotide (b)

Reduced flavin nucleotide + 2 Fe^{+++}-porphyrin → flavin nucleotide + 2 Fe^{++}-porphyrin + 2 H^+ (c

2 Fe^{++}-porphyrin + 2 H^+ + $\frac{1}{2}O_2$ → 2 Fe^{+++}-porphyrin + H_2O (d

Sum· Substrate + $\frac{1}{2}O_2$ → oxidized substrate + H_2O

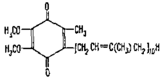
Reactions (b), (c) and (d) are referred to as the 'electron transport system' or the 'respiratory chain'.

There are many variants of this basic scheme, firstly, because there are two pyridine nucleotides, many flavoproteins (some containing nonhaem iron or molybdenum) and many iron porphyrins, secondly, because other types of reactions such as

flavoprotein 1 + reduced flavoprotein 2 → reduced flavoprotein 1 + flavoprotein 2

or

ferrous iron porphyrin 1 + ferric iron porphyrin 2 → ferric iron porphyrin 1 + ferrous iron porphyrin 2



Ubiquinone (Q_{10})

Other ubiquinones differ from this structure by the number of isoprenoid units in the side chain and are accordingly called Q_6, Q_8, Q_9, etc Hydrogen transfer by these coenzymes is effected by the reversible interconversion of the quinone and the hydroqui-

Fig 8 Diagram of the pathway of electron transport showing the stages where ADP is converted to ATP and where specific inhibitors act Electron carriers, the role of which cannot yet be clearly defined (ubiquinone, vitamin K, vitamin E) have been omitted Where the sequence in which the catalysts are arranged is uncertain they are bracketed together

substrates
↓
NADH

phosphorylating stage 1 { NADH → flavoprotein₁ → cytochrome b } Inhibited by chlorpromazine, barbiturates (amobarbital), rotenone

succinate ⟶ flavoprotein₂ ⟶ cytochrome b

phosphorylating stage 2 { cytochrome b → cytochrome c_1 → cytochrome c } Inhibited by *antimycin A*, 2 alkyl-4-hydroxyquinoline-*N*-oxide, 2,3-dimercaptopropanol (BAL = British Anti Lewisite), naphthoquinone, dihydroxystilbene

phosphorylating stage 3 { cytochrome c → cytochrome a, cytochrome a_3, copper → O_2 } Inhibited by cyanide, carbon monoxide, azide, sulphide

none. While the fact of reduction and reoxidation of ubiquinones is firmly established, the precise location of these catalysts in electron transport is not yet fully known. One of the places appears to be in the oxidation of succinate, another near cytochrome b[2]. There is evidence that vitamin E and vitamin K are also involved in the respiratory chain[5].

Figure 8 (page 403) illustrates schematically the pathway of electron transport and indicates the stages where ADP is converted to ATP and where specific inhibitors act.

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The key position of adenosine triphosphate (ATP) in biological energy transformations[1]

One of the outstanding advances in the understanding of energy metabolism is the appreciation of the fact that the energy derived from the degradation of foodstuffs can be utilized for most purposes only if it is first transformed into a special type of chemical energy. This is the energy residing in the pyrophosphate bonds of adenosine triphosphate (ATP), which is released when these bonds are hydrolysed to form inorganic orthophosphate (P) or pyrophosphate (PP), adenosine diphosphate (ADP) and adenosine monophosphate (adenylic acid, AMP):

$$\begin{array}{ccc} & \text{ATP} & \\ \swarrow & & \searrow \\ \text{ADP + P} & & \text{AMP + PP} \\ \downarrow & & \downarrow \\ \text{AMP + P} & & \text{P + P} \end{array}$$

Pyrophosphate bonds release more free energy on hydrolysis (11–13 kcal according to conditions) than ester–phosphate bonds (2–4 kcal). They are therefore referred to as 'energy-rich'. It is the hydrolysis of the pyrophosphate bonds of ATP that provides the energy necessary for the various kinds of work performed by living cells, such as the contraction of muscle, the production of secretions, the activities of the nervous system and the synthesis of cell constituents.

The pyrophosphate bonds used up during the activities of the cells are resynthesized at the expense of the energy liberated by the degradation of foodstuffs. The synthesis of pyrophosphate bonds may in fact be looked upon as the first major object of the biological energy transformations. Special chemical mechanisms are required for the coupling between pyrophosphate bond synthesis and foodstuff degradation. It is evident that many hundreds of separate reactions occur when foodstuffs are degraded, but o to the special arrangement of the metabolic processes couplin tween degradation and pyrophosphate bond synthesis occurs at a few stages. In all, six types of reaction are known in w energy becomes available for the synthesis of ATP. Two stages occur in anaerobic glycolysis: when one molecule of gl is converted into lactic acid two molecules of ATP are resy sized from ADP and inorganic phosphate (Table 3, page There are no more than four types of step in the course of al oxidative reactions where ATP is synthesized. The oxidative radation of the substrate itself, i.e., the removal of two hydr atoms and their transfer to pyridine nucleotide, as a rule doe supply energy. Energy is liberated when the hydrogen atom electrons are transferred from the pyridine nucleotides to mol lar oxygen through the reactions (**b**), (**c**) and (**d**) discussed page 403. Each of these three steps leads to the synthesis of pyrophosphate bond ('oxidative phosphorylation'). The fourth of the oxidative metabolism coupled with phosphorylation con of reactions of type (**a**) (page 403) where the substrate is an α-ket acid. Reactions of this type where the substrate is not an α-ket acid do not yield appreciable amounts of energy and therefore not support the synthesis of pyrophosphate bonds.

In spite of intensive studies, the chemical mechanism by wh the coupling between pyrophosphate synthesis and reactions (**c**) and (**d**) is effected is still essentially unknown. For review the present state of knowledge see the literature[3-5].

Some information is available about the coupling mechanism tween ATP synthesis and reactions of type (**a**) with α-ketonic ac as substrates. In this case an acyl-coenzyme A derivative is forn from the α-ketonic acid by the reactions described for pyruvate page 391. Thus α-ketoglutarate yields succinyl-coenzyme A. The ter reacts as follows:

succinyl-coenzyme A + guanosine diphosphate + P
→ succinate + coenzyme A + guanosine triphosphate

Phosphoryl succinate or phosphoryl-coenzyme A may be int mediates in this reaction though neither has as yet been identifie Guanosine triphosphate can transfer phosphate to ADP:

guanosine triphosphate + ADP
→ guanosine diphosphate + ATP

ATP contains two 'energy-rich' pyrophosphate bonds. It is pro able that only the terminal bond serves as an immediate source energy, or can be directly resynthesized. The second pyrophospha bond is used to re-phosphorylate ADP according to the reacti

$$2\,\text{ADP} \rightleftharpoons \text{AMP} + \text{ATP}$$

This reaction is catalysed by the enzyme adenylate kinase pre ent in all tissues. The balance of this reaction plus the hydrolysis ATP to ADP + P represents an hydrolysis of ADP to AMP + In reverse the reaction represents a mechanism for the re-phospho rylation of AMP.

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Digestive enzymes

This section describes the specific enzymes the combined action which is responsible for the digestion of foodstuffs Each enzyme catalyses the hydrolysis of one compound or of a series of closely related compounds (For a general review of enzymes and enzyme action see pages 382–386)

Proteolytic enzymes (proteases, peptide hydrolases peptidases])

These are enzymes catalysing the hydrolytic cleavage of peptide bonds

They may be divided into two main classes

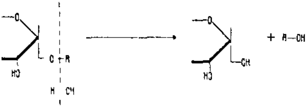
1 *Peptidyl-peptide hydrolases (endopeptidases)*, which act on proteins and peptides by hydrolysing 'internal' peptide linkages, i e , those situated away from the ends of peptide chains.

2 *α-Amino-acyl-peptide hydrolases, peptidyl-amino-acid hydrolases (exopeptidases)*, which catalyse the hydrolysis of peptide bonds situated at the ends of peptide chains These enzymes are specific for peptides possessing one or more free terminal α-amino or α-carboxyl groups

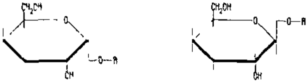
Members of both classes of proteases are widely distributed in mammalian tissues Those of the gastrointestinal tract are discussed in Tables 10 and 11, pages 406–409, those of other tissues in Table 12 (pages 410–411)

Glycoside hydrolases (glycosidases)

Carbohydrates are digested by these enzymes, which catalyse the hydrolysis of glycosidic bonds

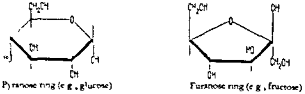


tential reducing group



α β

(c) the configuration (D or L) of the monosaccharide bearing the



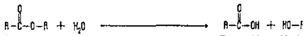
Pyranose ring (e g , glucose) Furanose ring (e g , fructose)

The general properties of mammalian glycoside hydrolases a described in Table 13 (pages 411–413). For their content in the m cosa of the human small intestine see page 413

Lipases and other ester hydrolases (esterases)

Fats and other esters are hydrolysed by the action of enzym that have been subdivided into

1 *Lipases*, thought to act predominantly on undissolved sul



Ester Fatty acid Alcoh

have similarly, like those of the gastrointestinal tract, they hydro lyse fats and short-chain fatty acid esters

Phosphoric ester hydrolases (phosphatases)

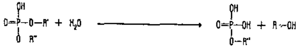
Mammalian tissues contain a variety of unspecific esterases whic have not yet been obtained in a pure form Some of these enzyme

fied as

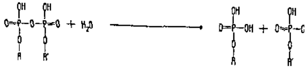
1 *Phosphoric monoester hydrolases* (phosphomonoesterases), hydro lysing monoesters of phosphoric acid

For example, glucose 6-phosphate is hydrolysed to glucose an phosphate

2 *Phosphoric diester hydrolases* (phosphodiesterases), hydrolysin substrates such as nucleic acids, or the synthetic substrate dipheny orthophosphate, at one of the ester linkages



3 *Pyrophosphatases*, hydrolysing the pyrophosphate linkages c salts of pyrophosphoric acid and of pyrophosphate esters



4 *Metaphosphatases*, hydrating metaphosphates to orthophos phates·

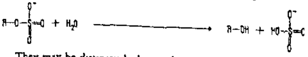
$(HPO_3)_n + n\,H_2O \rightarrow n\,H_3PO_4$

These have not been demonstrated to occur in the mammalia body

The phosphoric ester hydrolases are described in Table 15 (page 415–416), those acting on phospholipids and their metabolic prod ucts in Table 16 (page 417)

Sulphuric ester hydrolases (sulphatases)

These enzymes catalyse the hydrolysis of esters of sulphuric acid



They may be distinguished according to the nature of the sul phuric acid esters they hydrolyse

Nucleases

Ribonucleases (RNAases) and deoxyribonucleases (DNAases) catalyse the cleavage of ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) respectively (Table 17, pages 418–419). They are present in most if not all tissues.

Of the RNAases only pancreatic RNAase has been studied extensively. The enzyme is a specific phosphodiesterase hydrolysing certain phosphoric ester linkages of RNA but not of DNA. The end-products of the prolonged action of pancreatic RNAase are 3′-uridylic acid, 3′-cytidylic acid, and a large number of dialysable polynucleotides of varying degrees of polymerization. The terminal nucleotides of these polynucleotides are all either 3′-uridylic acid or 3′-cytidylic acid.

The initial action of RNAase on RNA probably involves mainly the 'phosphotransferase' action of the enzyme. The first step consists of the cleavage of the phosphodiester bond between the 3′- and 5′-positions of the ribose moieties of the RNA molecule, with the formation of oligonucleotides terminated by cyclic 2′,3′-phosphates. These terminal groups are split off (when the preceding unit in the RNA chain contains pyrimidine) as free mononucleotide cyclic phosphates and are then hydrolysed with the formation the corresponding nucleoside 3′-phosphate[2]. The mode of atta of the enzyme on a hypothetical part of an RNA molecule is show in Figure 9. Several enzymes have been reported to attack RN with the production of nucleoside 5′-phosphates.

Fig. 9 Reactions catalysed by pancreatic ribonuclease

The 5′-ester linkages attacked are indicated by broken arrows, those not attacked by crossed arrows. The enzyme does not attack 3′-ester linkages.

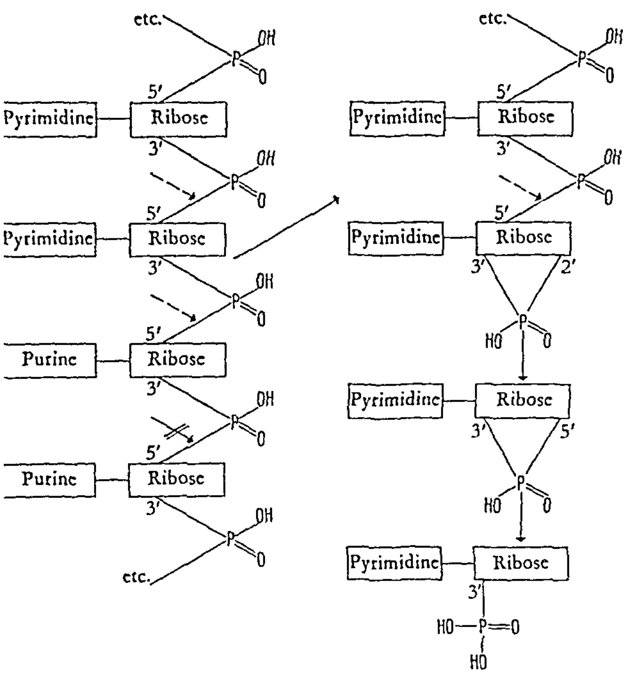
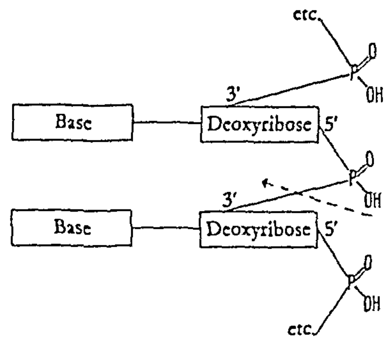


Fig. 10 The specificity of pancreatic deoxyribonuclease

The ester linkage attacked by the enzyme is indicated by a bro arrow.



Several types of DNAases are present in various tissues[3]; these, pancreatic DNAase (DNAase I) has been studied most exte sively. The enzyme is a specific phosphodiesterase that hydrolys certain phosphoric ester linkages of DNA. Some preparations ap pear to act also on RNA. The end-products of the prolonged actio of DNAase on DNA are mainly di- and tri-nucleotides as well a small amounts of mononucleotides and other polynucleotides. A the fragments produced are 5′-nucleotides. This indicates th pancreatic DNAase specifically hydrolyses nucleoside 5′-phospho diesters with the resulting liberation of the corresponding nucleo side 5′-phosphates (Figure 10). The enzyme appears to have preference for action on linkages between purine and pyrimidin nucleotides. A DNAase from spleen and thymus (DNAase II) differs from DNAase I in many of its properties. In particular DNA digestion by DNAase II produces more mononucleotides, considerably fewer dinucleotides, and much larger amounts of the higher oligonucleotides. All these reaction products are terminated by 3′-phosphates.

The products of the action of RNAase and DNAase are broken down further by other phosphodiesterases and phosphatases (see Table 17, pages 418–419) to yield nucleotides and nucleosides. The latter are then degraded by phosphorolysis to yield purines and pyrimidines and pentose 1-phosphate, or by hydrolysis to yield purines and pyrimidines, pentose and inorganic phosphate.

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Table 10 Peptidyl-peptide hydrolases (proteases) and their precursors in the gastrointestinal tract *(for references see page 408)*

Enzyme	Location	Approx. mol.wt.	Optimal pH of action	Reaction catalysed*	Remarks
Pepsinogen (enzyme precursor)	Chief cells of gastric mucosa	43 000	–	–	Formation of pepsin from pepsinogen is autocatalytic at pH <5 (maximally at pH 2)[1] with loss of (a) 'pepsin inhibitor', containing 29 amino acids, of mol.wt. 3242[2], and (b) 5 smaller peptides of aggregate mol.wt. ca. 4000[2,3]

* The specificity relationships listed are those elucidated by the action of the enzymes on synthetic peptides; they are not necessarily those of the enzymes acting on proteins *in vivo*.

le 10 (continued) Peptidyl-peptide hydrolases (proteases) and their precursors in the gastrointestinal tract

Enzyme*	Location	Approx. mol wt	Optimal pH of action	*Reaction catalysed***	*Remarks*
4.4 1 *psin*	Gastric juice	36 000	1 8–4 4 Depends on the nature of the substrate[4]	$-CO\,NH\,\overset{R}{CH}\,CO \mid NH\,\overset{R'}{CH}\,CO-$	Endopeptidase attacks most teins except some protamines keratins Denatured proteins [illegible] chain
4 4 2 *Pepsin B*[5]	Gastric juice	36 000	ca 3	Similar to pepsin	Formerly known as parapep *Differs from pepsin in the* terminal amino-acid residue, phosphorus content, and stability pH 6.9[6]
.4 4 22 *Gastricsin*[7]	Gastric juice	–	ca 3	Similar to pepsin	More heat-stable than pepsin has a lower electrophoretic mobility on starch gel; could be autolysis product of pepsin[7]
3 4 4 3 *Rennin*	Stomach of young animals	40 000	Milk clotting ca. 5, proteolysis (haemoglobin) 3 7[8]	Similar to pepsin[9] The crystalline enzyme (unlike commercial rennet) does not have phosphoamidase activity	Clots milk and liberates pept from the α-casein conta therein
Trypsinogen (enzyme precursor)	Pancreas	24 500[10]	–	–	Nonenzymatic precursor of trypsin, into which it is converted enteropeptidase and, autocatalytically, by trypsin, with elimination of a hexapeptide of structure V (Asp)₄–Lys from the N-term end by scission of a Lys–Ile b
3 4 4 4 *Trypsin*	Intestinal secretion	23 800	7–8	[illegible] L-arginine or L-lysine)	[illegible] soya beans[11]
Chymotrypsinogen A (enzyme precursor)	Acinar cells of pancreas	25 000[12]	–	–	Cationic at pH 8 (isoelectric p ca 9 1) Converted to δ-chymotrypsin via a sequence invol (a) cleavage of the Arg–Ile b of chymotrypsinogen A to f the highly active π-chymotryp (b) autolytic cleavage of a (sec bond of the C-terminal sequ of π-chymotrypsin, with elimination of the dipeptide serylargin to form δ-chymotrypsin[13] Subsequent attack, by autolysis and trypsin, may yield chymotryps A[14]
Chymotrypsinogen B[15] (enzyme precursor)	Acinar cells of pancreas	21 600[15]	–	–	Anionic at pH 8 (isoelectric p ca 5 2). Nonenzymic precurso chymotrypsin B

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 395 and 396).

** The specificity relationships listed are those elucidated by the action the enzymes on synthetic peptides, they are not necessarily those of enzymes acting on proteins *in vivo*

Table 10 (concluded) Peptidyl-peptide hydrolases (proteases) and their precursors in the gastrointestinal tract

Enzyme*	Location	Approx. mol. wt.	Optimal pH of action	Reaction catalysed**	Remarks
3.4.4.5 *Chymotrypsin A*	Pancreas	25 000	7.8	$-\mathrm{CO\cdot CH(R)\cdot NH}-\vert-\mathrm{CO\cdot CH(R')\cdot NH}-$ where for maximum activity R′ is phenyl or substituted phenyl. However, other bonds (such as L-leucyl or L-asparaginyl)[14] are also split at high rates	Derived from chymotrypsinoge A; contains three open peptic chains held together by disulphic bridges. Unlike trypsin, clots mil but not blood. Irreversibly inhib ited by *p*-nitrophenyl phosphate[1]
3.4.4.6 *Chymotrypsin B*	Pancreas	23 600[16]	ca. 8	Similar to chymotrypsin A	Unlike chymotrypsin A, splits acyl tryptophan esters very slowly i presence of 30% methanol[18]
3.4.4.7 *Pancreatopeptidase E*[19]	Pancreas	–	ca. 8	Hydrolyses peptide linkages, preferentially those adjacent to neutral L-amino-acid residues	Formerly known as elastase
3.4.4.8 *Enteropeptidase*	Intestinal secretion	–	ca. 6	Converts trypsinogen to trypsin	Exact mode of action unknown, since maximal activation of trypsinogen occurs under conditions where autocatalytic activation is also maximal. Enteropeptidase is probably a glycoprotein[20]

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386).

** The specificity relationships listed are those elucidated by the action of the enzymes on synthetic peptides; they are not necessarily those of the enzymes acting on proteins *in vivo*.

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Table 11 α-Aminoacyl-peptide hydrolases and peptidyl-amino-acid hydrolases in the gastrointestinal tract[1]

A large number of different exopeptidases have been recognized as occurring in the gastrointestinal tract. They are distinguished from each other mainly in their specificity of action on synthetic peptides. Relatively few have been purified extensively, and the list given here includes only those that have been well characterized.

Enzyme*	Location	Approx. mol. wt.	Optimal pH of action	Reaction catalysed**	Remarks
Dipeptidases: 3.4.3.1 *Glycyl-glycine dipeptidase* 3.4.3.6 *Iminodipeptidase* (prolinase) 3.4.3.7 *Imidodipeptidase* (prolidase)	Intestinal secretions	–	ca. 8	Hydrolyse dipeptides, with various degrees of specificity	The component members of this class of enzymes have not yet been sufficiently characterized to merit individual description. Glycyl-glycine dipeptidase[2] appears to be highly specific for this peptide linkage. Iminodipeptidase appears to act only on dipeptides which bear the free imino group of L-proline or hydroxy-L-proline[3], whereas imidodipeptidase splits peptide bonds involving the nitrogen of these compounds[2]

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386).

** The specificity relationships listed are those elucidated by the action of the enzymes on synthetic peptides; they are not necessarily those of the enzymes acting on proteins *in vivo*.

Table 11 (continued) α-Aminoacyl-peptide hydrolases and peptidyl-amino-acid hydrolases in the gastrointestinal tract

Enzyme*	Location	Approx mol wt.	Optimal pH of action	Reaction catalysed**	Remarks
Procarboxypeptidase A (enzyme precursor)	Acinar cells of pancreas	96 000	–	–	Nonenzymatic precursor of carboxypeptidase A. Is more acidic and larger than the enzyme to which it is converted by trypsin In this process, approx. 40 small peptides (average mol.wt. ca 1500) are released, but the enzymatic activity is confined to carboxypeptidase A
3 4 2 1 *Carboxypeptidase A*	Pancreatic juice	34 000	7 5–8 5	RCO –|– NH CH(R′) COOH Hydrolyses terminal peptide linkage adjacent to free carboxyl group. Though of wide specificity, maximally active when R′ = aromatic nucleus	Contains Zn (ca. 1 9 mg/g) as essential constituent
3 4 2 2 *Carboxypeptidase B*	Pancreatic juice	–	ca 8	RCO –|– NH CH(R′) COOH Acts uniquely on peptides containing R′ = arginine, lysine or ornithine. Again, carboxyl group must be free[4]	Formed from procarboxypeptidase B by tryptic activation[4], Probably identical with 'protaminase'[5]
3 4 1 1 *Leucine aminopeptidase*	Small intestine	300 000[6]	ca 8	H_2N CH(R) CO –|– NH CH(R′) COOH Wide specificity[7] ... tive when R = L- ... due. Also attacks p... but more slowly	Also found in other tissues, plants and micro-organisms. Activated by Mg^{++} or Mn^{++}, inhibited by anions ...
3 4 1 3 *Aminopeptidase*[2]	Small intestine	–	7 5–8 5	H_2N CH(R) CO –|– NH CH(R′) CO NH CH(R″) COOH Hydrolyses a w... tripeptides R... amino group	Hydrolyses tripeptides at the bond adjacent to the essential free ami...

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386)

** The specificity relationships listed are those elucidated by the action of the enzymes on synthetic peptides, they are not necessarily those of the enzymes acting on proteins *in vivo*

References

[1] For reviews see BOYER et al (Eds), *The Enzymes, 2nd ed, vol 4, Aca*demic Press, New York, 1960

[2] For a review see SMITH, E. L., *Advanc Enzymol*, 12, 191 (1951)

[3] DAVIS and SMITH, *J biol Chem*, 200, 373 (1953), DAVIS and ... , *Arch Biochem*, 57, 301 (1955)

[4] FOLK and GLADNER, *J biol Chem*, 231, 379 and 393 (1958)

[5] WEIL and TELKA, *Arch Biochem*, 71, ...

Table 12 Peptidyl-peptide hydrolases and exopeptidases in tissues other than the gastrointestinal tract

Enzyme*	Location	Optimal pH of action	Reaction catalysed**	Remarks
			Peptidyl-peptide hydrolases	
– *Cathepsins*** A and B*[1]	Ubiquitous component of animal tissues; particularly abundant in spleen, liver, kidney and lung	ca. 4 (A); 5–6 (B)	Similar in action to pepsin (A) and trypsin (B): can effect the activation of trypsinogen[2]	Whereas A requires no activ[ator] B has an absolute requiremen[t for] –SH compounds
3.4.4.9 *Cathepsin C*	Ubiquitous but most abundant in spleen	ca. 5 (at higher pH, catalyses transamidation reactions[3])	Similar in action to chymotrypsin but more restricted in its specificity: attacks only peptide linkages at a specified distance from the free α-amino group[3]	Activated by –SH compounds by cyanide
3.4.4.23 *Cathepsin D*[4]	Spleen	3.0 (acid-denatured haemoglobin); 4.2 (acid-denatured albumin)	Similar in action to pepsin, but more restricted in specificity	Does not hydrolyse the synth[etic] substrates[3] hydrolysed by cath[ep]sins A, B and C. The enzym[e is] heat-labile and rapidly destro[yed] below pH 2.5
3.4.4.13 *Thrombin*	Blood serum	ca. 7	Hydrolyses peptides, amides and esters of L-arginine; converts fibrinogen to fibrin	Formed from the nonenzymic p[re]cursor prothrombin by a vari[ety] of factors[5]
3.4.4.14 *Plasmin*	Blood serum	ca. 7	Hydrolyses peptides and esters of L-arginine and L-lysine; converts fibrin into soluble products	Formed from plasminogen[6]
			Exopeptidases	
3.4.3.1 *Glycyl-glycine dipeptidase*	Many tissues; has been partially purified from rat muscle, human uterus and swine kidney[7]	7.6	Similar in action to the intestinal enzyme	Activity enhanced by addition [of] Co^{++} or, more weakly, of $Mn^{+[+]}$ Preparations of this enzyme fro[m] rat muscle are exceedingly u[n]stable, from human uterus less sc
3.4.3.2 *Glycyl-leucine dipeptidase*	Several tissues; has been partially purified from uterus[7]	ca. 8	Similar in action to the intestinal enzyme	Activity enhanced by Zn^{++} a[nd] phosphate
3.4.3.3 *Carnosinase*	Several tissues; has been partially purified from spleen, liver and swine kidney[7,8]	8.0–8.4 in presence of Mn^{++}; 7.8–7.9 in presence of Zn^{++}; 7.4–7.5 in absence of metal	A dipeptidase, hydrolysing L-alanyl-L-histidine > glycyl-L-histidine > β-alanyl-L-histidine > D-alanyl-L-histidine	Activity enhanced by Zn^{++} an[d] Mn^{++}
3.4.3.6 *Iminodipeptidase* (prolinase)	Many tissues; has been partially purified from swine kidney[7]	ca. 8	Similar in action to the intestinal enzyme	Activity enhanced by Mn^{++} an[d] Cd^{++}
3.4.3.7 *Imidodipeptidase* (prolidase)	Many tissues; has been found in skeletal and smooth muscle, erythrocytes, serum, pituitary, lung and kidney, and has been partially purified from equine erythrocytes and swine kidney[7]	7.8–8.0	Similar in action to the intestinal enzyme	Activity enhanced by Mn^{++}
3.4.2.1 *Carboxypeptidase A*	Most animal tissues	ca. 7	Homospecific with pancreatic carboxypeptidase A	Old name: cathepsin IV

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386).

** The specificity relationships listed have been elucidated by the use of synthetic substrates; they are not necessarily those of the enzymes acting on proteins *in vivo*.

*** The term 'cathepsin' is applied to proteinases obtained from tissues other than the gastrointestinal tract. None of them has yet been crystallized and their physiological role is not established.

Table 12 (continued) Peptidyl-peptide hydrolases and exopeptidases in tissues other than the gastrointestinal tract

Enzyme*	Location	Optimal pH of action	Reaction catalysed**	Remarks
		Exopeptidases (continued)		
3.4 1.1 *Leucine aminopeptidase*	Many tissues; especially abundant in kidney	8–9	[illegible]	[illegible]
3 4.1.3 *Aminopeptidase*	Most animal tissues	8 0	Similar in action to intestinal tripeptidase	Inhibited by cysteine, Cd^{++}, Hg^{++}. Rapidly inactivated in acid media

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386)

** The specificity relationships listed have been elucidated by the use of synthetic substrates, they are not necessarily those of the enzymes acting on proteins *in vivo*

References

[1] For a review see Fruton, J S , in Boyer et al (Eds), *The Enzymes*, 2nd ed , vol 4, Academic Press, New York, 1960, page 233
[2] Greenbaum et al , *J biol Chem* , 234, 2885 (1959)
[illegible]

Table 13 Glycosyltransferases and glycoside hydrolases (glycosidases) *(for references see page 413)*

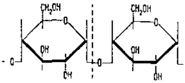
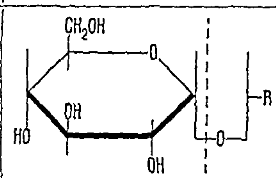
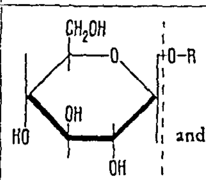
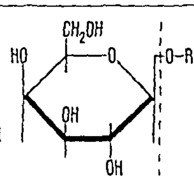
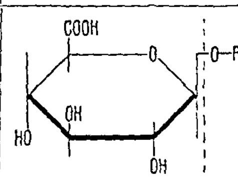
Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
2 4 1.1 *α Glucan phosphorylase*[1] (glycogen phosphorylase)	Muscle, liver	6 9	Transfers D-glucose residues from non-reducing end of starch or glycogen chains to inorganic phosphate, D-glucose or oligosaccharides α-D-glucose 1-phosphate + $[G]_n$ $\rightleftharpoons [G]_{n+1} + H_3PO_4$	Acts on glycogen and amylopectin Phosphorolysis of exterior chains giving 20–44% α-D-glucose 1-phosphate from various glycogens and 35–55% from various amylopectins and leaving a phosphorylase limit dextrin (Φ-dextrin). Most phosphorylases exist in more than one form, an *a* form active in the absence of adenosine 5′ phosphate and a *b* form dependent on adenosine 5′-phosphate for activity Pyridoxal 5′-phosphate is a prosthetic group for *a* and *b* forms Interconversion of *a* and *b* forms is an enzymic process involving the action of a specific phosphatase ($a \rightarrow b$) or a phosphokinase ($b \rightarrow a$) This change is accompanied by a gross change in molecular size
3 2 1 1 *α-Amylase*[1]	Saliva, pancreatic juice, blood	6 9		Hydrolyses in a random manner non-terminal α-1,4-glucosidic bonds in amylose, amylopectin, glycogen and dextrins The initial stage of action of the [illegible] ucts of the enzyme reaction are maltose (70–90%), small amounts of D glucose, and α limit dextrins consisting of 4–8 glucose units and containing one or more α-1,6-glucosidic linkages[2]. The α-amylases are calcium metalloproteins whose activity is enhanced by $Cl^- > Br^- > I^- > NO_3^-$

Table 13 (continued) Glycosyltransferases and glycoside hydrolases (glycosidases)

Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
3.2.1.10 *Oligo-1,6-glucosidase*[3]	Small intestine	6.3	Hydrolyses 1,6-glucoside linkages of isomaltose, panose, and α-amylase dextrins	Participates in the digestion of starch by hydrolysing the α-amylase limit-dextrins to smaller unbranched molecules that can be further degraded by α-amylase and α-glucosidase in the pancreatic juice. Has no action on glycogen, phosphorylase limit-dextrin or maltose
3.2.1.33 *Dextrin-1,6-glucosidase*[4] (a similar enzyme from plants is listed 3.2.1.9)	Muscle	ca. 7	Hydrolyses the outermost inter-chain linkages in a phosphorylase limit-dextrin to give glucose + polysaccharide	Originally known as amylo-1,6-glucosidase. Hydrolyses the α-1,6-glucosidic bonds of the limit-dextrin resulting from phosphorylase action. The enzyme liberates glucose plus a polysaccharide that can again be degraded by phosphorylase action. The concurrent action of dextrin-1,6-glucosidase and phosphorylase gives complete breakdown of the polysaccharide yielding >90% α-D-glucose 1-phosphate and D-glucose (4–8%) from the α-1,6-linked residues. This enzyme differs from oligo-1,6-glucosidase in having no action on isomaltose, panose, or α-amylase limit-dextrin. In the relative absence of this enzyme, as in type 3 glycogen-storage disease (see pages 450 to 451), glycogen breakdown is incomplete and limited to the exterior chains
3.2.1.20 *α-Glucosidase*	Small intestine, pancreatic juice, blood, liver	6.6–7.0	 where R = glucose (in which case the compound is maltose), substituted hexoses, phenols, terpenes, etc.	Formerly called maltase: the maltose produced from the digestion of starch by α-amylase is hydrolysed to glucose by this enzyme. Inhibited by the glucose formed. Certain α-glucosidases hydrolyse sucrose and others do not. At least three intestinal 'maltases' have been separated from 'isomaltase'[3,6]
3.2.1.21 *β-Glucosidase* 3.2.1.23 *β-Galactosidase*[5]	Kidney, liver, small intestine, blood	ca. 6	 and 	β-Glucosidase is widespread in plants and micro-organisms. In some preparations it appears to be identical with β-galactosidase[7]. β-Galactosidases can transfer galactose residues to a variety of acceptors (such as lactose, galactose and glucose) as well as to water
3.2.1.31 *β-Glucuronidase*[8]	All mammalian tissues and body fluids; especially high in liver, kidney, spleen, epididymis and cancer tissues	ca. 5	 Hydrolyses steroid glucuronides and various β-glucuronides excreted in urine and bile	Possibly plays a role in mucopolysaccharide metabolism. Hydrolyses alkyl, aryl, alicyclic and acyl β-glucuronides and some β-galacturonides. Aldonolactones are powerful competitive inhibitors of the enzyme. Dilute solutions of the enzyme are activated non-specifically by a variety of high molecular weight compounds, the most reliable results being given by albumin. No action on α-glucuronides or β-glucosides. Shows some transferase reaction *in vitro* but unlikely to be of importance in glucuronide synthesis *in vivo*. After the action of testicular hyaluronidase on hyaluronic acid or chondroitin, the oligosaccharides formed are degraded stepwise from the non-reducing end by β-glucuronidase and β-acetylglucosaminase (below) acting alternately

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385–386).

13 (*concluded*) Glycosyltransferases and glycoside hydrolases (glycosidases)

Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
.1.35 *aluronate lyase* hyaluroni-dase)[9]	Testes	ca. 7	[illegible]	[illegible] products of action on chondroitin sulphates are tetrasaccharides, apparently still 4- and 6-sulphate esters The hyaluronidase contained in the head of most mammalian spermatozoa probably plays a role in their penetration through the granulosa cell layer of the ovum
2.1 17 *Mucopeptide glucohydrolase*[10] (lysozyme)	Tears, nasal mucus, saliva, blood serum and plasma	6 2	[illegible]	[illegible] a role in defending mucus surfaces against bacterial invasion
3 2 1.19 *Heparinase*[11]	Liver and kidney	5 3–6 8	Hydrolyses α-1,4 links between D-glucosamine sulphate and D-glucuronic acid residues in heparin	A similar enzyme isolated from bacteria has been used to elucidate the structure of heparin[12]
3 2.1.30 β-*Acetylglucosaminase*[13]	Spleen, liver, kidney, lung, blood, heart, brain, testes	4 0–6 0	[illegible]	[illegible] glucose residues from A but not from 0(H)[14] The same enzyme may act on β-acetylgalactosaminases

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386).

References

1 Manners, D J, *Advan Carbohyd Chem*, 17, 371 (1962)
2 Walker and Whelan, *Biochem J*, 76, 257 (1960)
[illegible]
10 [illegible] New York, 1966, page 447.
11 [illegible]
12 [illegible]
13 [illegible]
14 [illegible]

Glycoside hydrolases of the mucosa of the human small intestine[1]

Age	Number	Protein (mg/g mucosa)	Enzyme activity (U/g protein)*					
			'Maltase'	'Saccharase'	'Isomaltase'	'Lactase'	'Cellobiase'	'Amylase'
Gestational age								
2–3 months	2	42.5	12.5 (2 1–23)	4 (0 6–7.5)	4 (0 6–7.4)	1	–	–
3–4 months	3	51 (47–55)	104 (80–124)	40 (34–48)	36 (36–37)	7 (5–9)	–	5
6 months	1	90	132	52	44	15	4 1	6 6
7–8 months	6	96 (58–150)	235 (100–431)	91 (31–201)	74 (35–145)	26 (15–37)	5 8 (4 4–8 5)	11.4 (8–18)
8–9 months	10	90 (77–129)	281 (138–422)	101 (51–150)	85 (37–113)	31 (16–77)	6 6 (3 2–16.2)	16 5 (8 8–32
Adults	15	90 (84–121)	246 (70–456)	76 (24–152)	74 (27–136)	30 (5 9–54 5)	6 8 (1–11.6)	205 (78–117

* 1U = 1 μmol disaccharide hydrolysed per minute at 37 °C and pH 5 8

1 Auricchio et al, *Pediatrics*, 35, 944 (1965)

Table 14 Fatty acid ester hydrolases (fatty acid esterases)

Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
3.1.1.1 *Carboxylesterase*[1]	Most tissues, high activity in liver	ca. 8	Hydrolyses carboxylic esters to give a carboxylic acid and an alcohol	Formerly called aliesterase. Hydrolyses di solved triglycerides. Much more active c simple esters (e.g., methyl butyrate) tha on acetylcholine. All esterases can catalys the transfer of the acyl moiety of the sub strate. In the presence of hydroxylamin the liver enzyme catalyses the formation c hydroxamic acids from fatty acids[2]
3.1.1.3 *Lipase*[3]	Pancreas, gastric juice, saliva	7–9	CH_2—O—CO—R CH—O—CO—R' CH_2—O—CO—R'' where R, R' and R'' are long-chain fatty acids. Attacks tri- > di- > monoglycerides	Splits preferentially the outer chains of the triglyceride so that hydrolysis proceeds via triglyceride → 1,2-diglyceride → 2-mono glyceride → glycerol. Pancreatic lipase acts only at an ester–water interface. Suspensions of methyl butyrate and triacetin are readily hydrolysed but the enzyme does not attack true solutions of methyl butyrate. Bile salts activate the enzyme, in part by emulsifying the water-insoluble substrate. The optimum reaction for hydrolysis of lower triglycerides is about pH 7. For higher triglycerides it is pH 8.8
3.1.1.6 *Acetylesterase*[1]	Widely distributed	ca. 7	Hydrolyses acetic esters to give an alcohol and acetic acid	Also attacks aromatic acetates. Less sensitive to eserine inhibition than cholinesterase
3.1.1.7 *Acetylcholinesterase*[4]	Most tissues, especially conductive tissues (e.g., brain, nerves), erythrocytes	ca. 7	Hydrolyses acetylcholine to give acetic acid and choline. Hydrolyses propionylcholine at the same rate but butyrylcholine only slowly	Has a well-defined optimum substrate concentration for acetylcholine of 4–7 µmol/ml and is inhibited at higher concentrations. Acetyl-β-methylcholine is rapidly hydrolysed, but the rate is considerably lower than with acetylcholine. Acts on a variety of acetic esters and catalyses transacetylations
3.1.1.8 *Cholinesterase*[5]	Most tissues, especially blood serum, pancreas, liver, ovary, placenta, intestinal mucosa, brain	ca. 7	Hydrolyses acylcholine to give choline and an acid	Hydrolyses butyryl- or propionylcholine more rapidly than acetylcholine. Also hydrolyses simple butyryl or propionyl esters. Does not act on acetyl-β-methylcholine. Does not have a well-defined substrate optimum, i.e., is not inhibited by excess substrate. The cholinesterases can be distinguished from the simple esterases by the effect of eserine (physostigmine). All types of cholinesterase are completely inhibited by 10^{-5}-molar eserine
3.1.1.13 *Cholesterol esterase*[6]	Pancreas, blood serum	ca. 8	Hydrolyses cholesterol esters to give cholesterol and an acid	The enzyme from pancreas has an absolute requirement for free cholic acid. The enzyme is much less stable than lipase. Purified enzyme has synthetic as well as hydrolytic activity. Cholesterol, dehydroandrosterone, dihydrocholesterol and cholestanol are readily esterified and all the sterol butyrates are rapidly hydrolysed. Cholesterol esterase may be identical with one of the carboxylesterases of the pancreas

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386).

References

[1] Hofstee, B.H.J., in Boyer et al. (Eds.), *The Enzymes*, 2nd ed., vol. 4, Academic Press, New York, 1960, page 485.

[2] Lipmann and Tuttle, *Biochim. biophys. Acta (Amst.)*, 4, 301 (1950).

[3] Desnuelle, P., *Advanc. Enzymol.*, 23, 129 (1961).

[4] Wilson, I.B., in Boyer et al. (Eds.), *The Enzymes*, 2nd ed., vol. 4, Academic Press, New York, 1960, page 501.

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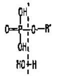
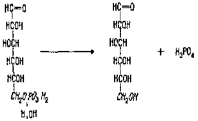
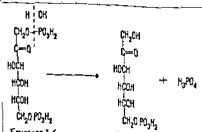
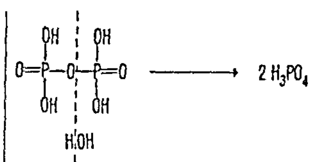
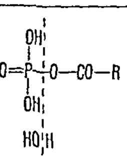
[6] Hernandez and Chaikoff, *J. biol. Chem.*, 228, 447 (1957).

ble 15 Phosphatases

Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
			3.1.3 Phosphoric acid monoester hydrolases (phosphomonoesterases)	
1 3.1 *Alkaline phosphatase*[1]	Most cells, particularly zones of growth of bones, intestinal mucosa, kidney, lactating mammary gland, milk	9–10, depending on substrate and concentration		Has wide specificity. Activity is enhanced by divalent cations, e g , Mg^{++}. In contrast to certain other groups of hydrolases, phosphomonoesterhydrolases and phosphodiesterases are not inhibited by di-isopropyl fluorophosphate. The enzyme shows transferase activity. In hypophosphatasia abnormally low amounts of the enzyme are present in all tissues and in blood serum In bone destruction the amount in blood serum is considerably increased Might serve to provide inorganic phosphate for metabolic, excretory and some secretory purposes
3 1.3 2 *Acid phosphatase*[2]	Lactating mammary gland, kidney, prostate, liver, spleen, erythrocytes	5 3–5 6	As for alkaline phosphatase	Has wide specificity Many but not all acid phosphatases catalyse transfer of the phosphoryl group to organic hydroxyl compounds Of the animal acid phosphatases only the enzyme from prostate glands is inhibited by (+) tartrate
3 1 3 9 *Glucose-6-phosphatase*[3]	Liver, kidney, small intestine	6 5	 Glucose 6-phosphate → Glucose	Readily catalyses the transfer of a phosphoryl group from glucose 6-phosphate to glucose or fructose Hydrolytic activity is inhibited by glucose Appears to be solely associated with the microsomal fraction Plays a role in the formation of glucose from glycogen and noncarbohydrate compounds (see Fig 17, page 441) Absent from, or weak in, the liver during glycogen storage disease[4]
3 1 3 11 *Hexosediphosphatase*	Kidney, liver	9 3–9 5	 Fructose 1,6 diphosphate → Fructose 6-phosphate	Markedly specific for fructose 1,6-diphosphate[5] Does not hydrolyse glucose 1-phosphate, glucose 6-phosphate, fructose 6-phosphate, L-sorbose 1-phosphate or phosphoglycerate Fructose 1-phosphate and L-sorbose 1,6-diphosphate are hydrolysed at rates of 0 009 and 0 03 times the rate for fructose 1,6-diphosphate respectively The enzyme is activated by Mg^{++} or Mn^{++} and inhibited by fructose 6-phosphate, fructose 1,6-diphosphate and adenosine monophosphate Plays a role in the synthesis of glycogen from noncarbohydrate compounds (see Fig 17, page 441)

* Π

Table 15 (continued) Phosphatases

Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
			3.1.4 Phosphoric acid diester hydrolases (phosphodiesterases)	
3.1.4 *Phosphodiesterases*	Widespread	–	Hydrolyses phosphoric diesters to a phosphoric monoester and an alcohol	The enzymes classified as phosphodiesterases are listed elsewhere, e.g., glycerophosphorylcholine diesterase, phospholipase C and phospholipase D in Table 16 opposite, and ribonuclease, deoxyribonuclease and phosphodiesterase in Table 17, page 441
			3.6.1 Hydrolases acting on anhydrides containing phosphoryl	
3.6.1.1 *Inorganic pyrophosphatase*[6]	Liver, brain, erythrocytes and other tissues	7.6–7.8		Has an absolute requirement for Mg^{++}. Some tissues contain a pyrophosphatase with an acid pH optimum, and this enzyme is not stimulated by Mg^{++}
3.6.1.7 *Acylphosphatase*[7]	Skeletal muscle, brain, kidney, liver, leucocytes	5.3	 where R·CO = acetyl, butyryl, palmityl	Also catalyses the hydrolysis of 1,3-diphosphoglyceric acid and carbamyl phosphate. No reaction with glycerol phosphate, 3-phosphoglycerate or phosphoenolpyruvate. Stable to heat at acid pH values (no loss of activity after 15 min at 80 °C). Has a molecular weight of ca. 13000 and is similar to ribonuclease both in size and in its remarkable stability to various denaturing agents
3.6.1.9 *Nucleotide pyrophosphatase*[8]	Kidney, liver	ca. 8	Hydrolyses dinucleotides to give 2 mononucleotides	Acts rapidly on $NADH_2$, $NADPH_2$, FAD, adenosine diphosphate ribose and several analogues of $NADH_2$. The animal enzyme generally splits $NADH_2$ faster than NAD. The enzyme from potato also splits ADP, ATP and thiamine pyrophosphate

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386).

References

1 Stadtman, T.C., in Boyer et al. (Eds.), *The Enzymes*, 2nd ed., vol. 5, Academic Press, New York, 1961, page 55.
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Table 15 (continued) Phosphatase

Enzyme*	Location
3.1.4 *Phosphodiesterases*	Widespread
3.6.1.1 *Inorganic pyro-phosphatase*[6]	Liver, brain, erythrocytes other tissues
3.6.1.7 *Acylphosphatase*[7]	Skeletal mus brain, kidne liver, leucoc
3.6.1.9 *Nucleotide pyro-phosphatase*[8]	

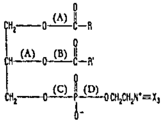
, and trivial names an
of the International U

).

[7] STADTMAN, T.C., in BOYER et al. (E
demic Press, New York, 1961, pag

16 Phospholipases

Typical phospholipids, such as lecithin or cephalin, may be represented by the general formula



where $R{-}\overset{O}{\overset{\|}{C}}{-}O$ is a saturated, $R'{-}\overset{O}{\overset{\|}{C}}{-}O{-}$ an unsaturated, long chain fatty acid, $X = CH_3$ for lecithin, H for cephalin. The corresponding enzymes capable of cleaving the four designated bonds in the formula are called phospholipases A, B, C and D. Since the term 'lipase' usually refers to the cleavage of a carboxyl ester, phospholipases C and D are in a strict sense phosphodiesterases.

Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
.1 4 *...spholipase A*[1]	Muscle, heart, liver, kidney, adrenals, pancreas	ca 7	[illegible]	[illegible] without loss of activity. Cleaves the phospholipid–cytochrome complex within mitochondria, causing powerful inhibition of certain respiratory enzymes
1 5 *...ospholipase B*[1] (lysophospholipase)	Liver, pancreas	4 0–6 0	[illegible]	[illegible]
1 4 3 *...osopholipase C*	*Clostridium* toxins, brain[2]	6 0–7 6	[illegible]	[illegible] ...retains 50% of its activity after heating at 100°C for 10 min
1 4 4 *...hospholipase D*	Not present in mammalian tissues Found in plants[3]	5 1–5 9	Cleavage of the phospholipid at the po... marked (D) in the ...mula	Catalyses [illegible] ...g at 100°C for 15 min
1 4 2 *...lycerophosphoryl ...oline diesterase*	Nervous tissue[4], liver and other tissues[5]	7 5 9 0	–	Catalyses hydrolysis of glycerol phosphorylcholine, produced by the joint action of phospholipase A and B, to glycerol phosphate and choline. Resembles phospholipase D in specificity. Also acts on glycerophosphoethanolamine Requires Mg^{++} The enzyme has been purified from bacterial extracts

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 386)

References
1 Slotta K H in [illegible]
2 [illegible]
3 [illegible]
4 [illegible]
5 [illegible]

Table 17 Nucleases and other enzymes acting on nucleotides and nucleosides

Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
2.7.7.16 *Ribonuclease*[1] (RNAase)	Most tissues, highest activity in the pancreas *RNAase content of vertebrate pancreas* (μg/g)[11] Cow 1200 Sheep 1080 Goat 1000 Mouse 395 Lizard 380 Rat 260 Guinea-pig 240 Pig 80 Horse 25 Chicken 20 Whale 18 Monkey 2 Man 1 Cat 0.5 Dog 0.5 Rabbit 0.5	7.0–8.0	Catalyses the depolymerization of ribonucleic acid, producing nucleoside 3'-phosphates. The animal enzymes cannot attack purine nucleoside phosphate linkages and consequently produce a resistant 'core' rich in purine bases	First action of RNAase on internucleotic bonds is transesterification to form a py rimidine nucleoside cyclic 2',3'-phospha ester. These terminal groups are split off a free mononucleotide cyclic phosphate which are then hydrolysed with the forma tion of the corresponding nucleoside 3' phosphates. Some enzymes produce nu cleoside 5'-phosphates from RNA. Bovin pancreatic RNAase has been extensivel studied
3.1.4.5 *Deoxyribonuclease*[2] (DNAase) 3.1.4.6 *Deoxyribonuclease II*[2] (DNAase II)	Many tissues, pancreas being the best source	ca. 7 4.5–5.5	Catalyse the depolymerization of deoxyribonucleic acids. Products include mononucleotides through to oligonucleotides. All four mononucleotides have been isolated from the enzyme digests. The nucleotides are terminated in 5'-phosphates in the case of DNAase and 3'-phosphates in the case of DNAase II	DNAase requires added Mg^{++} for activity, is inhibited by EDTA and has a pH optimum at ca. 7. DNAase II is inhibited by added Mg^{++}, often activated by EDTA and has a pH optimum at pH 4.5–5.5. Both DNAases can occur in the same tissue
3.1.4.1 *Phosphodiesterase*[3]	Intestine, spleen and other tissues	ca. 7	Hydrolyses phosphoric diesters to give a phosphoric monoester and an alcohol	Attacks both ribo- and deoxyribo-internucleotide bonds. Has wide specificity. The spleen enzyme forms 3'-nucleotides
3.1.3.5 *5'-Nucleotidase*[4]	Retina, nervous tissue, prostate, testes, sperm. In human tissues the highest activity is in the posterior pituitary gland	ca. 8	Hydrolyses all ribonucleoside and deoxyribonucleoside 5'-phosphates as well as nicotinamide mononucleotide to the corresponding nucleosides and orthophosphate	Preparations of the enzyme, especially from snake venom and bull seminal plasma, have been used to help establish the identity of nucleoside 5'-phosphates
2.4.2.1 *Purine nucleoside phosphorylase*[5]	Liver, brain, thymus, erythrocytes and other tissues	ca. 7	Pentose 1-phosphate + purine $\rightleftharpoons$ nucleoside + orthophosphate	Since the reaction is readily reversible the enzyme is often assayed as orthophosphate released on nucleoside formation. At least two classes of enzymes, purine and pyrimidine nucleoside phosphorylases, have been recognized. The specificity of the various enzymes has not been completely determined. It seems likely that these enzymes play a role in nucleic acid breakdown rather then in nucleoside synthesis

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385–386).

Table 17 (continued) Nucleases and other enzymes acting on nucleotides and nucleosides

Enzyme*	Location	Optimal pH of action	Reaction catalysed	Remarks
3.5.4.6 *AMP deaminase*[6]	Muscle and other tissues	6.1–6.4	Deaminates adenylic acid to inosinic acid and ammonia	Acts only on 5'-adenylic acid and 5'-deoxyadenylic acid. The rate with the latter is about 1% of that with the former
3.5.4.4 *Adenosine deaminase*[7]	Muscle, liver, intestinal mucosa	ca. 7.5	Deaminates adenosine to inosine and ammonia	Deoxyadenosine is also deaminated
3.5.4.3 *Guanine deaminase*[7,8]	Liver, muscle	6–10	Deaminates guanine to xanthine and ammonia	[illegible] to determine micro-amounts of guanine
1.2.3.2 *Xanthine oxidase*[9]	Milk, liver, spleen, kidney, lung	7.4	The purified enzyme oxidizes hypoxanthine to xanthine, xanthine to uric acid, and aldehydes to acids	Contains flavin adenine dinucleotide, iron and molybdenum
1.7.3.3 *Urate oxidase*[10]	Liver and kidney of mammals. Absent in man and other primates	9.2	Oxidizes uric acid to allantoin according to the overall reaction uric acid + O_2 + $2H_2O$ → allantoin + H_2O_2 + CO_2	Contains copper. The production of allantoin is dependent on the interaction of the reaction intermediates with the buffer ions. In phosphate and tris buffers the product is allantoin alone but in borate buffer only 30% of the product is allantoin

* The numbers and trivial names are those recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385 and 396).

References

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[9] [illegible]

Synthesis of cell constituents

Apart from supplying energy, the products of digestion serve as precursors of many cell constituents. The mammalian body can form all cell constituents from:

1. The essential amino acids (see page 434)
2. Vitamins
3. The essential (highly unsaturated) fatty acids
4. Mineral salts
5. A bulk source of carbon (usually carbohydrate)
6. A source of nitrogen in the form of ammonia derived mainly from surplus amino acids, with small amounts supplied by purine bases, pyrimidines and amino sugars.

Carbohydrate as a bulk source of carbon can be largely replaced by protein and fat, especially in carnivores.

Much progress has been made in recent years in the elucidation of the pathways by which the basic constituents of food are converted into cell constituents, but many details still remain to be clarified. A synopsis of the available information is contained in the section which follows.

Synthesis of cell constituents from glucose

The principal products, their pathways of formation and their physiological functions are summarized in Table 18 below.

The oxidative pentose phosphate cycle

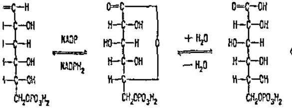
Glucose 6-phosphate (formed from glucose by the hexokinase reaction) can be oxidized in liver and some other animal tissues at the carbon atom 1 to yield 6-phosphogluconate. This initiates a sequence of reactions in which various pentose phosphates and other sugar phosphates are formed. In the course of these reactions

Table 18 Formation of basic cell constituents and metabolites from glucose

Product formed	Pathway of formation	Physiological function
Glycogen	From glucose 1-phosphate via UDP-glucose, catalysed by UDPG pyrophosphorylase and UDPG glycogenglucosyltransferase[1]	Storage of carbohydrate
Galactose	Reversal of reactions 4 and 5, Table 4, page 390	Constituent of lactose, cerebrosides
Lactose	Probably from UDP-galactose and glucose 1-phosphate, via lactose 1-phosphate	Milk constituent
Ribose 5-phosphate	Reactions of the pentose phosphate cycle (see opposite page)	Constituent of nucleic acid and nucleotides
Deoxyribose 5-phosphate	Probably by aldol condensation between glyceraldehyde phosphate and acetaldehyde (reversal of the reaction shown on page 399)	Constituent of nucleic acids
Glucuronic acid and iduronic acid	Formed via UDP-glucose (see page 423)	Constituent of mucins (hyaluronic acid and chondroitin sulphate) and of heparin; detoxicating agent
Glucosamine	From fructose 6-phosphate by transfer of the amido group of glutamine (see page 423)	Constituent of lipids, polysaccharides and glycoproteins
L-Fucose	From fructose 6-phosphate via GDP-mannose (see page 423)	Constituent of milk oligosaccharides and glycoproteins
Fructose	Reactions of glycolysis and hydrolysis of fructose 6-phosphate by phosphatase	Constituent of semen
Citric acid	CO_2-fixation by pyruvate (see page 424) and reactions of the tricarboxylic acid cycle (see page 390)	Constituent of bone, milk, semen
Fatty acids	From acetyl-coenzyme A (formed via pyruvate) by a route involving malonyl-coenzyme A	Constituents of fats and phospholipids
Glycerophosphates	Reduction of dihydroxyacetone phosphate, catalysed by glycerophosphate dehydrogenase	Constituents of phospholipids
Phospholipids	See page 425	Cell constituents
Glyceride fats	See page 426	Cell constituents
Sterols and steroids	See pages 426–432	Cell constituents; hormones
Nonessential amino acids:		
Glutamic acid	Glutamate dehydrogenase reaction (see page 432)	Constituent of proteins and special peptides (glutathione, folic acid)
Aspartic acid	CO_2-fixation by pyruvate (see page 424) and transamination between glutamate and oxaloacetate	Constituent of proteins
Alanine	Transamination between pyruvate and glutamate	Constituent of proteins
Glycine	From 3-phosphoglycerate by the reactions shown on page 432	Constituent of proteins
Serine	From 3-phosphoglycerate by the reactions shown on page 432	Constituent of proteins
Cysteine	From serine by transsulphuration from homocysteine derived from methionine (see pages 397–398)	Constituent of proteins
Proline	From glutamic acid or ornithine (see page 432)	Constituent of proteins
Hydroxyproline	Probably by oxidation of proline (see page 432)	Constituent of proteins

me glucose 6-phosphate is regenerated, implying a cyclic nature the reaction sequence. The reactions of this cycle represent a

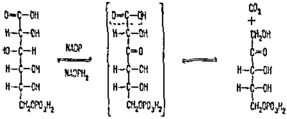
tion.



(1)

lucose phosphate — 6-Phosphoglucono-lactone — 6 Phosphogluconic acid

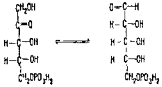
The 6-phosphogluconate formed is oxidatively decarboxylated l) to yield ribulose 5-phosphate, while another molecule of NADP is reduced[2]



(2)

5 Phospho-gluconic acid — Hypothetical intermediate (3 keto 6 phosphogluconic acid) — Ribulose 5 phosphate

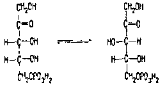
Ribulose 5 phosphate undergoes two different isomerizations, one to ribose 5-phosphate (3) catalysed by pentose phosphate isomerase[3]



(3)

Ribulose 5 phosphate — Ribose 5 phosphate

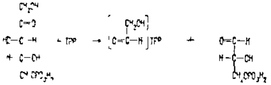
and one (4) to xylulose 5-phosphate[4,5]



(4)

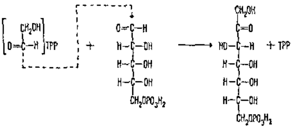
Ribulose 5 phosphate — Xylulose 5-phosphate

This may therefore be written as

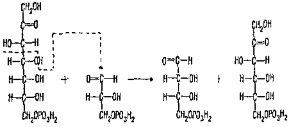


(5)

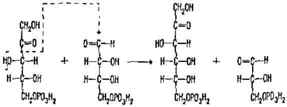
Xylulose 5 phosphate — 'Active glycolaldehyde' — Glyceraldehyde 3 phosphate



'Active glycolaldehyde' — Ribose 5 phosphate — Sedoheptulose 7-phosphate

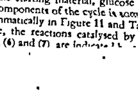


Sedoheptulose 7-phosphate — Glyceraldehyde 3 phosphate — Erythrose 4 phosphate — Fructose 6 phosphate



Xylulose 5-phosphate — Erythrose 4 phosphate — Fructose 6 phosphate — Glyceraldehyde 3 phosphate

The fructose 6-phosphate formed in reactions (6) and (7) is co verted to glucose 6-phosphate by reaction (8), catalysed by gluc phosphate isomerase



Fructose 6 phosphate — Glucose 6-phosphate

This reaction completes the cycle in that it leads to the (part regeneration of the starting material, glucose 6-phosphate. T interplay of the components of the cycle is somewhat complex is shown diagrammatically in Figure 11 and Table 19 (page 4 In this scheme, the reactions catalysed by transketolase transaldolase, (5), (6) and (7) are indicat

glucose 6-phosphate → glyceraldehyde 3 phosphate + 3 CO

Table 19 The component reactions of the pentose phosphate cycle and their quantitative relations

(1)	3 glucose 6-phosphate + 3 NADP	(glucose 6-phosphate dehydrogenase) →	3 6-phosphogluconate + 3 $NADPH_2$
(2)	3 6-phosphogluconate + 3 NADP	(phosphogluconate dehydrogenase) →	3 ribulose 5-phosphate + 3 CO_2 + 3 NADPH
(3)	ribulose 5-phosphate	(ribosephosphate isomerase) →	ribose 5-phosphate
(4)	2 ribulose 5-phosphate	(ribulosephosphate 3-epimerase) →	2 xylulose 5-phosphate
(5)	ribose 5-phosphate + xylulose 5-phosphate	(transketolase) →	sedoheptulose 7-phosphate + glyceraldehyde 3-phosphate
(6)	sedoheptulose 7-phosphate + glyceraldehyde 3-phosphate	(transaldolase) →	fructose 6-phosphate + erythrose 4-phosphate
(7)	xylulose 5-phosphate + erythrose 4-phosphate	(transketolase) →	fructose 6-phosphate + glyceraldehyde 3-phosphate
(8)	2 fructose 6-phosphate	(glucosephosphate isomerase) →	2 glucose 6-phosphate
Sum	glucose 6-phosphate + 6 NADP	→	3 CO_2 + glyceraldehyde 3-phosphate + 6 $NADPH_2$

Fig. 11 Diagram of the pentose phosphate cycle

Starting materials and end-products are shown enclosed. P = phosphate. The crossing arrows indicate transfer reactions. For further details see Table 19 and the text.

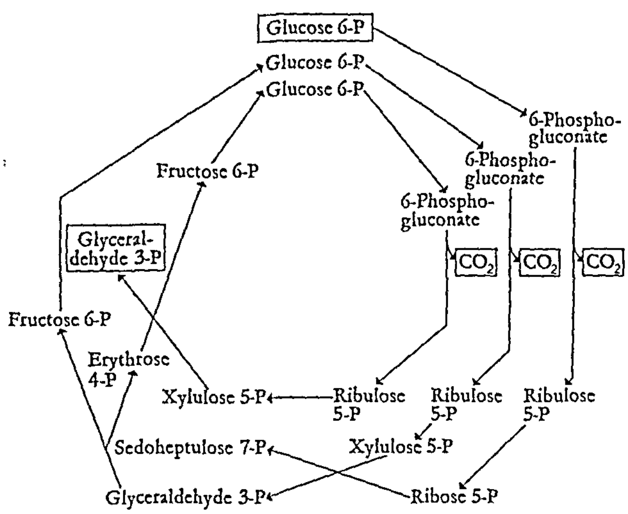
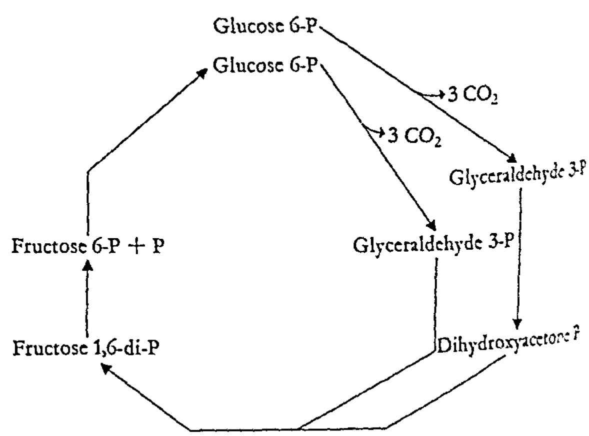


Fig. 12 Complete oxidation of glucose 6-phosphate via the pe[ntose] phosphate cycle and additional reactions catalysed b[y] triosephosphate isomerase, fructosediphosphate aldolas[e,] hexosediphosphatase and glucosephosphate isomerase

The first step shown in the diagram (conversion of glucose 6-phos[s]phate into glyceraldehyde phosphate + 3 CO_2) represents the su[m] of the reactions shown in Table 19 and Figure 11. P = phosph[ate]



The glyceraldehyde 3-phosphate thus formed does not, however, accumulate in the organism. It can be converted into pyruvate and acetyl-coenzyme A and undergo complete oxidation. Alternatively, if triosephosphate isomerase, fructosediphosphate aldolase, hexosediphosphatase and glucosephosphate isomerase are present, the following sequence of reactions can occur:

glyceraldehyde 3-phosphate	→ dihydroxyacetone phosphate	(9)
glyceraldehyde 3-phosphate + dihydroxyacetone phosphate	→ fructose 1,6-diphosphate	(10)
fructose 1,6-diphosphate + H_2O	→ fructose 6-phosphate + H_3PO_4	(11)
fructose 6-phosphate	→ glucose 6-phosphate	(8)

Glucose 6-phosphate would thus be formed from two molecules of glyceraldehyde 3-phosphate, and could re-enter (and be oxidized by) the pentose phosphate cycle. Reactions (1)–(11) repeated several times would therefore result in a complete combustion of glucose 6-phosphate. This concept, which rests on the demonstration of all the required enzymes in liver[11], is illustrated in Figure 12.

Physiological significance of the oxidative pentose phosphate cycle. The oxidative pentose phosphate cycle is not a major source of energy. Its function is probably twofold: to supply (1) pentose phosphates required for the synthesis of nucleic acids, and (2) reduced NADP required as a source of hydrogen in many reductive syntheses. Quantitatively, the most important reductive synthesis in animal tissues is the formation of fatty acids from carbohydrates, and this is in accordance with the fact that the activity of the enzymes of the pentose phosphate cycle is particularly high at the sites of lipogenesis, for instance in the lactating mammary gland and in adipose tissue[12].

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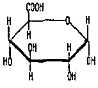
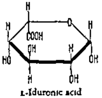
..., *Angew Chem* 73 771 (1961) Holzer et al *Ann N Y Acad* [illegible]

Glucuronic acid and iduronic acid



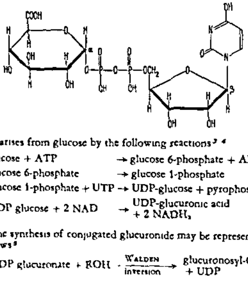
D-Glucuronic acid



L-Iduronic acid

D-Glucuronic acid and L-iduronic acid are components of mucopolysaccharides, such as the chondroitin sulphates. Glucuronic acid is also a coupling agent in detoxication reactions. It couples [illegible] and with bile pigments[2].

The reactive form of glucuronic acid in the conjugation reactions, in the synthesis of mucopolysaccharides and in the interconversion of glucuronic and iduronic acids is UDP-glucuronic acid:



This arises from glucose by the following reactions[3,4]

glucose + ATP → glucose 6-phosphate + ADP

glucose 6-phosphate → glucose 1-phosphate

glucose 1-phosphate + UTP → UDP-glucose + pyrophosphate

UDP glucose + 2 NAD → UDP-glucuronic acid + 2 $NADH_2$

The synthesis of conjugated glucuronide may be represented as follows[5]

$$\text{UDP glucuronate} + \text{ROH} \xrightarrow[\text{inversion}]{\text{Walden}} \text{glucuronosyl-OR} + \text{UDP}$$

where ROH is an alcoholic or phenolic compound, or an aromatic carboxylic acid.

UDP-glucuronic acid is converted to uridine diphosphoiduronic acid by an epimerase that attacks the 5-position of the sugar ring. NAD acts catalytically[4].

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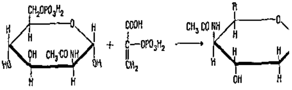
Formation of glucosamine and related amino sugars

Glucosamine, mannosamine, and their N-acetyl derivatives, as well as sialic acid, occur in lipids, polysaccharides and glycoproteins. Glucosamine is formed from fructose 6-phosphate by transfer of the amido group of glutamine. The amino sugar i[s] acetylated by an enzymatic reaction involving acetyl-coenzy[me A]

fructose 6-phosphate + glutamine → glucosamine 6-phosphate + glutamic acid

glucosamine 6-phosphate + acetyl-coenzyme A → N-acetylglucosamine 6-phos[phate] + coenzyme A

The sugar *N*-acetylglucosamine is converted to *N*-acetylma[nnos]amine, which is then phosphorylated with ATP to yield [a] phosphate derivative. This reacts with phosphoenolpyruv[ate to] yield a sialic acid

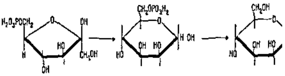


R = —CH(OH)·CH(OH) CH

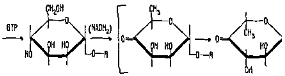
N-Acetylmannosamine 6-phosphate | Phosphoenol-pyruvate | *N*-Acetylneurami[nic] acid 9-phosphate (a sialic acid)

Biosynthesis of L-fucose in mammalian tissues[1]

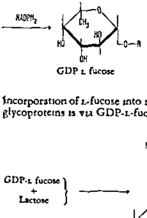
L-Fucose is formed from fructose 6-phosphate by the foll[owing] series of reactions (R = GDP residue)



D-Fructose 6 phosphate | D-Mannose 6-phosphate | D-Mannose 1-ph[osphate]



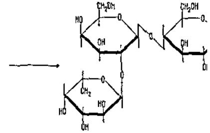
GDP-D-mannose | GDP-4-keto-6-deoxy-D-mannose | GDP-4-keto-6 deoxy L-galact[ose]



GDP L fucose

Incorporation of L-fucose into milk oligosaccharides and p[r] glycoproteins is via GDP-L-fucose.

GDP-L fucose + Lactose →



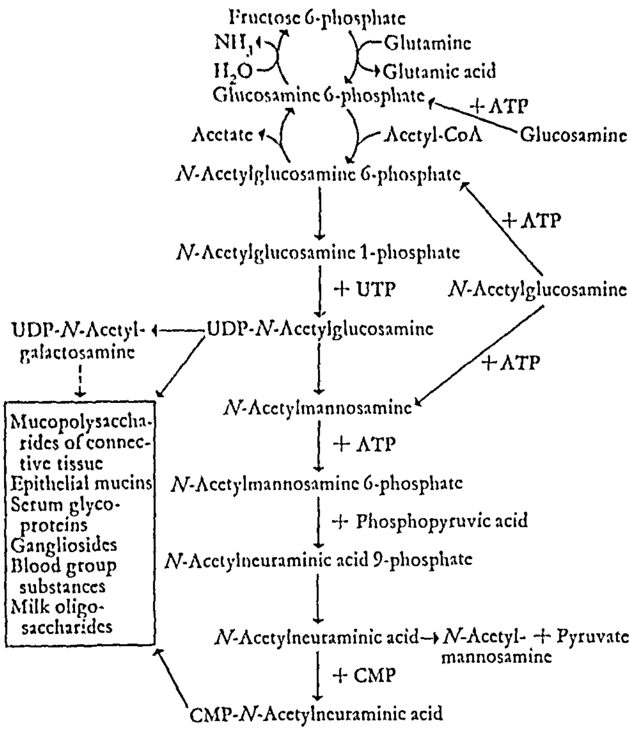
Fucosidolactose (2 [α-L-fuco-pyranosido]lactose)

Referen[ces]

[1] ...

Formation and utilization of hexosamines and *N*-acetylneuraminic acid in mammals

The following scheme illustrates the manner in which these amino sugars[1] are formed and utilized in the mammalian organism:



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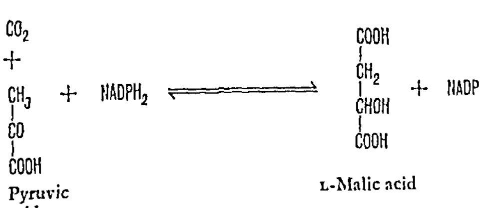
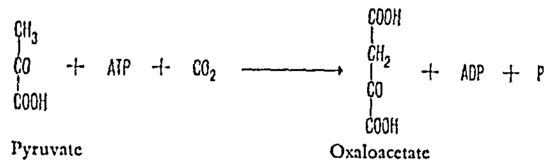
[1] On amino sugar metabolism in general see Wolstenholme and O'Connor (Eds.), *Ciba Foundation Symposium on the Chemistry and Biology of Mucopolysaccharides*, Churchill, London, 1958; Roseman, S., *Ann.Rev.Biochem.*, 28, 545 (1959); Gottschalk, A., *The Chemistry and Biology of Sialic Acids and Related Substances*, Cambridge University Press, London, 1960; Whitehouse and Zilliken, *Meth.biochem.Anal.*, 8, 199 (1960); Clark and Grant (Eds.), *The Biochemistry of Mucopolysaccharides of Connective Tissue*, Biochem. Soc.Symp., No.20 (1961); Stacy and Barker, *Carbohydrates of Living Tissues*, Van Nostrand, London, 1962; McGarrahan and Maley, *J.biol. Chem.*, 237, 2458 (1962); Spiro, R.G., *New Engl.J.Med.*, 269, 566 (1963); Symposium on Mucous Secretions, *Ann.N.Y.Acad.Sci.*, 106, 157 (1963); Brimacombe and Webber, *Mucopolysaccharides*, Elsevier, Amsterdam, 1964; Dorfman, A., *Biophys.J.*, 4, suppl., 155 (1964); Ginsburg, V., *Advanc. Enzymol.*, 26, 35 (1964); Grant and Simkin, *Ann.Rep.chem.Soc.*, 61, 491 (1964); Kornfeld et al., *Proc.nat.Acad.Sci.(Wash.)*, 52, 371 (1964); Sarcione, E.J., *J.biol.Chem.*, 239, 1686 (1964); Carter et al., *Ann.Rev.Biochem.*, 34, 109 (1965); Molnar et al., *J.biol.Chem.*, 240, 1882 (1965); Jeanloz and Balazs (Eds.), *The Amino Sugars*, 2 vols., Academic Press, New York, 1965/66; Gottschalk, A., *Glycoproteins*, Elsevier, Amsterdam, 1966.

Extension of carbon chains by carbon dioxide fixation

An important link in the building-up of the carbon skeletons of cell constituents is the addition of CO_2 to pyruvate. There are at least two CO_2-fixation reactions in animal tissues by which 4-carbon chains arise from pyruvate. The first[1] is catalysed by the 'malic' enzyme; it requires reduced NADP and leads to L-malic acid:



The second reaction requires ATP and consists of the carboxylation of pyruvate to oxaloacetate, catalysed by the enzyme pyruvate carboxylase[2]:



Both reactions readily occur in liver tissue and also elsew They are reversible. The malic and oxaloacetic acids forme enter the tricarboxylic acid cycle and form citrate and α glutarate.

References

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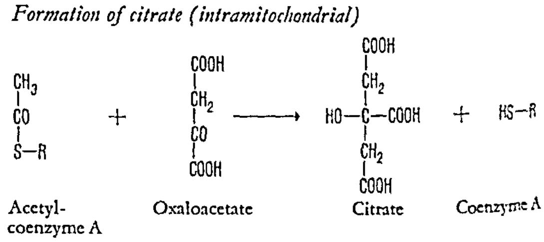
Fatty acid synthesis

Acetyl-coenzyme A formed from carbohydrate or amino a if not required for energy supply or special biosyntheses, ca converted to fatty acids. Most of the acetyl-coenzyme A is for within the mitochondria, but the synthesis of fatty acids is an e mitochondrial process[1]. Acetyl groups must therefore be dive from the mitochondria to the extramitochondrial space. Thi quires a special mechanism since acetyl-coenzyme A as such ca diffuse into or out of the mitochondria[2]. The acetyl group is p ably transferred as follows[3]:

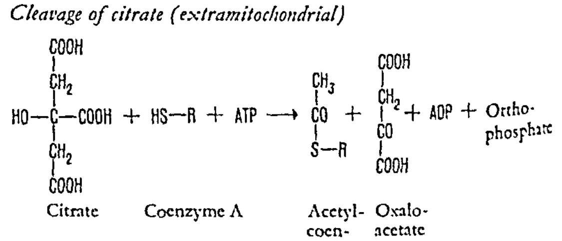
Formation of citrate (intramitochondrial)



Diffusion

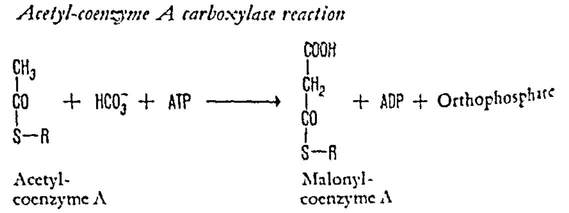
Intramitochondrial citrate → extramitochondrial citrate

Cleavage of citrate (extramitochondrial)



It is to be noted that reactions (1) and (3) are catalysed by different enzymes[4]. Reaction (3) is followed by the carboxylation of acetyl-coenzyme A to yield malonyl-coenzyme A[5]:

Acetyl-coenzyme A carboxylase reaction



The enzyme catalysing this reaction contains biotin and requires citrate as an activator. Acetyl-coenzyme A and malonyl-coenzyme A then condense and are reduced according to the following stoichiometric equation[6]:

$$\text{acetyl-CoA} + 7\ \text{malonyl-CoA} + 14\ NADPH_2 \rightarrow \text{palmitate} + 7\ CO_2 + 14\ NADP + 8\ \text{CoA}$$

action is catalysed by a cytoplasmic enzyme complex[7] con- of at least 6 or 7 different kinds of protein; these are tightly together in yeast and pigeon liver but readily dissociable in ind several plant systems. An 'acyl carrier protein' (ACP) n isolated from *E coli* which binds acyl intermediates during mation of long-chain fatty acids. ACP contains one free dryl group per molecule, derived from 2-mercaptoethyl- which binds the acyl derivative to form a thioester[8]. The ual steps of the fatty acid synthesis in *E.coli* are as follows

·l S CoA + HS ACP	→	acetyl S ACP + HS CoA	(5a)
›nyl S CoA + HS ACP	→	malonyl S ACP + HS CoA	(5b)
/l S ACP + malonyl S ACP	→	acetoacetyl S ACP + HS ACP + CO_2	(5c)
oacetyl S ACP + $NADPH_2$	→	D-β-hydroxybutyryl S ACP + NADP	(5d)
hydroxybutyryl S ACP	→	crotonyl S ACP + H_2O	(5e)
onyl S ACP + $NADPH_2$	→	butyryl S·ACP + NADP	(5f)

ryl S ACP then undergoes condensation with another mole-

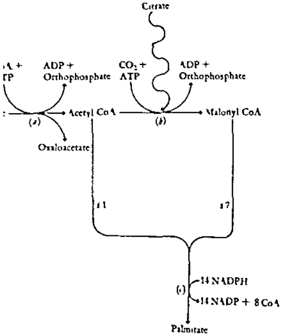
nityl S ACP + HS CoA	→	palmityl S CoA + ACP	(5g)

: palmityl group of palmityl CoA may then be hydrolysed to ate or transferred to α-glycerophosphate and related com- ls

›s (3), (4) and (5) of this process are summarized in Figure 13

3 Fatty acid synthesis from citrate

(*a*) Citrate cleavage enzyme (*b*) Acetyl coenzyme A carboxylase (activated by citrate) (*c*) Enzyme complex



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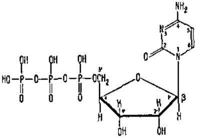
Formation of lecithin and cephalin

The synthesis of lecithin in animal tissues from fatty acids, glycerophosphate and choline requires the participation as cofactors of ATP, coenzyme A and cytidine triphosphate.



Cytidine triphosphate

The intermediary stages of the synthesis are as follows.

(*a*) 'Activation' of fatty acids[1,2]

RCOOH + HSR′ + ATP ⟶ RCOSR′ + AMP + pyrophosphate
Fatty acid, Coenzyme A, Acyl-coenzyme A

(*b*) 'Activation' of choline by choline kinase[2]

$CH_2N(CH_3)_3$ / CH_2OH + ATP ⟶ $CH_2N(CH_3)_3$ / $CH_2OPO_3H_2$ + ADP
Choline, Phosphocholine

(*c*) 'Activation' of phosphocholine[3]

cytidine triphosphate + phosphocholine ⇌ cytidine diphosphocholine + pyrophosphate

(*d*) Synthesis of phosphatidic acid[3]

CH_2OH / $CHOH$ / $CH_2OPO_3H_2$ + R′COSR + R″COSR ⟶ CH_2OCOR' / $CHOCOR''$ / $CH_2OPO_3H_2$ + 2 HSR
α Glycerophosphate, 2 Acyl-coenzyme A, Phosphatidic acid, 2 Coenzyme A

(*e*) Dephosphorylation of phosphatidic acid[3].
phosphatidic acid → D-α,β-diglyceride + phosphate

(*f*) Synthesis of lecithin[3].
cytidine diphosphocholine + D-α,β-diglyceride → lecithin + cytidine monophosphate

(*g*) Rephosphorylation of cytidine monophosphate[4]
cytidine monophosphate + 2 ATP → cytidine triphosphate + 2 ADP

Cephalin is synthesized by analogous reactions, choline being replaced by ethanolamine (HO CH_2 CH_2 NH_2)

References

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Formation of triglyceride[1]

The synthesis of triglyceride requires α-glycerophosphate. Two molecules of fatty acyl-coenzyme A condense with α-glycerophosphate to form phosphatidic acid, and then diglyceride, as described in the previous section. The final step is the reaction of diglyceride with another molecule of fatty acyl-coenzyme A to form triglyceride:

$$\begin{array}{l} CH_2OCOR' \\ | \\ CHOCOR'' \\ | \\ CH_2OH \end{array} \quad + \quad RCOSR \quad \longrightarrow \quad \begin{array}{l} CH_2OCOR' \\ | \\ CHOCOR'' \\ | \\ CH_2OCOR \end{array} \quad + \quad HSR$$

Diglyceride	Fatty acyl-coenzyme A	Triglyceride	Coenzyme A

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Biosynthesis of cholesterol[1]

Cholesterol[2] is by far the commonest sterol of the animal kingdom, though related sterols, notably Δ^7-sterols, are found to predominate in some primitive molluscs and starfish. Cholesterol is synthesized in almost all vertebrate tissues but most actively in the liver, intestine, adrenals and gonads. Synthesis does not take place in erythrocytes, and is reduced to extremely low levels in nerve and brain after myelination is completed. An important function of cholesterol is as a component of cell membranes and subcellular membrane structures, in which it is associated with phospholipids, glycolipids and proteins. The most likely type of interrelationship of these different components in membranes has been deduced from studies of the structure and composition of the myelin sheath and the erythrocyte membrane.

The rate of endogenous cholesterol synthesis is variable and in man has been estimated to range between 0.5 and 2 g per day[21]. The principal catabolic pathway for cholesterol is conversion to bile acids by the liver[22]. Some intact cholesterol leaves the body by excretion into the bile and some by direct loss through the intestinal wall and faeces. In the intestine some cholesterol is metabolized to coprosterol and coprostanone. A small proportion of the total cholesterol synthesized functions as a precursor of the steroid hormones of the adrenal cortex and of the steroid sex hormones.

The pathway of synthesis of cholesterol[3,4] has been studied primarily in the rat. Certain important reaction steps[5] have been studied *in vitro* with enzymes isolated from yeast, which synthesizes the related sterol, ergosterol. All the evidence assembled so far points to a unified mechanism of synthesis for the basic structure of all sterols. The sterols of plants (e.g., β-sitosterol) and fungi (e.g., ergosterol) differ from cholesterol in having extra carbon atoms in the side chain. These carbon atoms are added at a late stage in the synthesis by a mechanism so far not completely elucidated[6].

The individual steps in the biosynthesis of cholesterol as understood at present are as follows (Fig.14 opposite):

The molecule is built up from acetate units which condense in the form of their coenzyme A derivatives; the first condensation yields acetoacetyl-coenzyme A (I), the second involves the further condensation of this compound with a third acetyl-coenzyme A molecule to give hydroxymethylglutaryl-coenzyme A (II). For several years it was recognized that by some mechanism this product must yield a five-carbon 'isoprenoid' fragment which forms the basis of the sterol structure, but it was only with the discovery of mevalonic acid (III) and the subsequent study of its conversion to sterol[7] that the details of this mechanism could be clarified. Hydroxymethylglutaryl-coenzyme A (II) is now known to be reduced by an NADP-dependent enzyme system to mevalonic acid (III). The occurrence of an aldehydic intermediate in this reduction is not certain. Mevalonic acid next undergoes at least two sequential phosphorylations yielding in turn mevalonic phosphate (IV) and mevalonic pyrophosphate (V), the phosphate group at each step being derived from a molecule of ATP. A third molecule of ATP is consumed in the next reaction, in which mevalonic pyrophosphate (V) undergoes both dehydration and decarboxylation to isopentenyl pyrophosphate (VII)[8]. This transformation probably involves the intermediate formation of the triphosphate (VI), but this compound has not been identified.

An isomerase converts the isopentenyl pyrophosphate (VII) to its dimethylallyl isomer[9] (VIII), and a condensation reaction between dimethylallyl pyrophosphate and isopentenyl pyrophosphate now takes place to give geranyl pyrophosphate (IX). This compound in turn condenses with a further dimethylallyl pyrophosphate molecule to give farnesyl pyrophosphate[10] (X). Each of these condensations takes place with elimination of the pyrophosphate group as the inorganic ion and the formation of a new double bond lying in the main chain allylic to the remaining pyrophosphate group. The steps probably involved in the first of these reactions are shown (VII + VIII). The second condensation (IX + VIII) follows by an analogous mechanism.

In some manner as yet undetermined, two molecules of farnesyl pyrophosphate condense to form the C_{30} triterpenoid hydrocarbon squalene (XI). This condensation is known to involve stereospecific addition of hydrogen from reduced NADP[11]. Squalene now undergoes a series of ill-defined cyclization and rearrangement reactions ending in lanosterol[12] (XII), with 2,3-oxidosqualene as intermediate[23].

Comparison of the structures of lanosterol (XII) and cholesterol (XIX) shows that the remaining biosynthetic steps must involve the removal of three methyl substituents from the 4α-, 4β- and 14α-positions of lanosterol. Other necessary changes are the saturation of the double bond in the side chain and the conversion of the Δ^8-to the Δ^5-nuclear structure. The three 'extra' methyl groups appear to be removed prior to the other changes in the molecule. In the pathway operating in the rat, the 14α-methyl group is removed first[13] and the two methyl substituents in position 4 are then removed in turn. The carbon atoms detached from the nucleus in these reactions are converted to CO_2[14] and the oxidation of each methyl to a carboxylic acid group seems likely to occur in each case. The final decarboxylation step is thought to be facilitated in the case of the 14α-methyl group by the proximity of the Δ^8-bond and in the case of the C_4-methyl groups by the transitory oxidation of the 3β-OH group to a ketone. Evidence for the latter step is the fact that the loss of the 4α-methyl group takes place with exchange of the 3α-hydrogen atom (demonstrated with 3α-tritium labelled substrates)[15].

The demethylation steps, if they occurred with no other changes in the molecule, would lead to the formation of $\Delta^{8,24}$-cholestadienol-(3β) (zymosterol) (XV). This compound is known as a minor sterol of yeast and evidence for its participation in the biosynthesis of cholesterol in the rat has been given[16]. The steps involved in the conversion of the Δ^8-structure of zymosterol to the Δ^5-structure of cholesterol are still unclear at many points. It seems likely that the Δ^8-bond is shifted to Δ^7 by some 'direct' mechanism involving hydrogen transfer. The conversion of Δ^7-cholestenol-(3β) to cholesterol probably takes place via the $\Delta^{5,7}$-derivative and is known to require oxygen, but the participation of a 6-hydroxylated derivative has not been demonstrated.

It has been suggested that in rat liver the conversion of zymosterol to cholesterol takes place via the $\Delta^{7,24}$-, $\Delta^{5,7,24}$- and $\Delta^{5,24}$-intermediates (XVI–XVIII) respectively, with the final step in the biosynthesis of cholesterol involving reduction of the Δ^{24}-bond[4]. The $\Delta^{5,24}$-sterol desmosterol (XVIII), known to occur naturally in trace amounts in adult mammalian tissues[17] and in larger amounts in embryonic chick tissues[18], accumulates in the liver of rats treated with the anticholesterogenic drug triparanol[19]. However, the question of whether the Δ^{24}-bond is retained until the last step in cholesterol synthesis must be regarded as unsettled at the present time. Evidence presented by several laboratories indicates that all the conversions from lanosterol onwards can be accomplished by enzymes of rat liver with substrates in which the Δ^{24}-bond is either present or absent. Moreover, normal rat skin contains a complex mixture of sterols with a saturated side chain but with nuclear structures representing nearly all the possible stages in the conversion of lanosterol to cholesterol. Triparanol treatment leads to the accumulation of the Δ^{24}-analogues of all these compounds in the skin[20]. It is possible that there are differences between tissues that determine whether cholesterol biosynthesis takes place predominantly via the Δ^{24}-series of compounds, including desmosterol (XVIII), or via the series of analogues in which the side chain is saturated, but whether it is necessary to envisage the process as occurring by one or the other of two mutually exclusive pathways is not clear.

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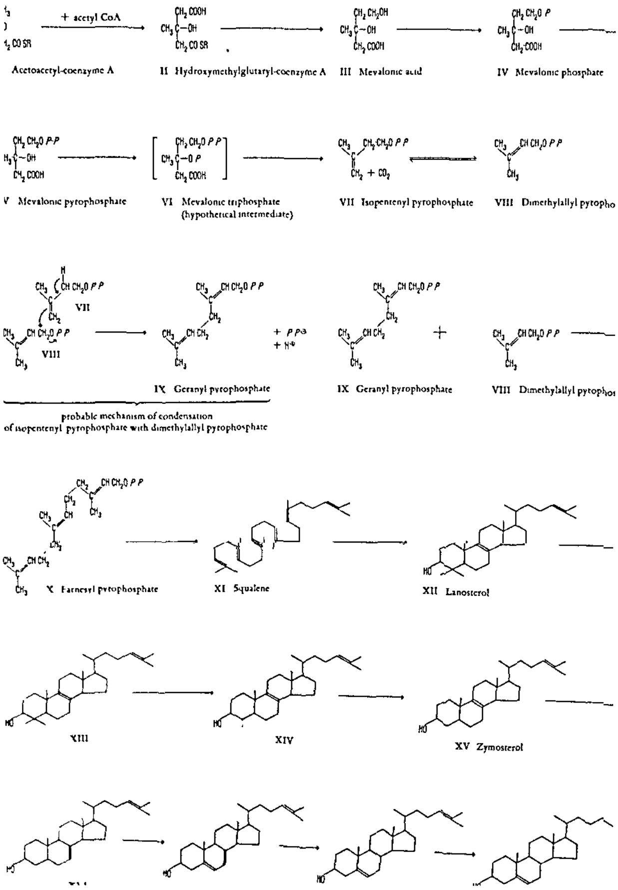
ig. 14 Biosynthesis of cholesterol



[3] Popják and Cornforth, *Advanc.Enzymol.*, 22, 281 (1960).
[4] Bloch, K., *Vitam.and Horm.*, 15, 119 (1957).
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Biosynthesis and metabolism of steroid hormones of the adrenal cortex and gonads (for references see page 430)

The normal adrenal cortex produces a wider variety of steroid hormones than either the ovary or the testis[1]. Besides producing eight C_{21}-steroids of known structure and proven 'corticoid' activity, it also produces many C_{21}-steroids of unknown physiological activity as well as progesterone, the oestrogens and the androgens of the $C_{19}O_2$- and $C_{19}O_3$-series[2–4]. Adrenal androgen formation[5] is at present more fully documented than the formation of adrenal oestrogens, and the pathway of testicular androgen formation appears to be clearly represented in the adrenal cortex. It is therefore convenient to outline the pathways of androgen synthesis together with the pathways of synthesis of C_{21}-steroids in a single scheme (Fig. 15), since these two aspects of steroid metabolism are closely interlinked. The oestrogenic steroids are further transformation products of the androgens and are more conveniently discussed separately (see page 430). The adrenal cortex, the testis, the ovary and the placenta are all capable of synthesizing their characteristic steroid hormones from acetate via cholesterol and pregnenolone, and it seems likely that most of the biosynthetic reactions involved in the synthesis of all classes of steroid hormones are possible in all the above-mentioned organs. However, it is not certain to what extent the hormones secreted normally in vivo are formed from acetate, from blood cholesterol or from steroid precursors synthesized in the adrenal cortex.

The C_{21}-corticoids have profound effects on carbohydrate and protein metabolism ('glucocorticoid' activity) and on sodium and potassium metabolism ('mineralocorticoid' activity). Most of these compounds exert effects of both types with one or the other predominating, according to their chemical structure. The more powerful glucocorticoids are those having oxygen functions at both C-11 and C-17. The glucocorticoid action of the human adrenal is considered to be accounted for almost wholly by the cortisol (hydrocortisone) it produces, since this is both the most potent naturally occurring steroid in this respect and also the most abundant product of the adrenal cortex in man. Corticosterone, the most abundant corticoid of the rat, has a less powerful glucocorticoid action. It is now clear that a portion of the cortisol or corticosterone output of the adrenal is in a protein-bound form in the blood[6]. It seems probable that the unbound portion is to be regarded as the physiologically active form, and various factors (for instance oestrogen levels) affecting the degree of protein-binding of the glucocorticoids may therefore exert important effects on their physiological function. The most potent hormone in the regulation of salt metabolism is aldosterone, a quantitatively minor product. Deoxycorticosterone has a much smaller but still detectable effect on salt metabolism. For further discussion of the adrenocortical steroids see pages 742 sq.

Figure 15 shows the most probable routes of biosynthesis of the physiologically active C_{21}-steroids of the adrenal and depicts the main pathways leading to the androgens testosterone, Δ^4-androstenedione, dehydroepiandrosterone, 11β-hydroxy-Δ^4-androstenedione and Δ^4-androstene-3,11,17-trione (adrenosterone). All these C_{19}-steroids may arise in the adrenal but the last two, having 11-oxygen functions, are probably specifically products of the adrenals. Testosterone is certainly the principal androgen of the testis but probably is formed in only trace amounts in the adrenal. Both the testis and adrenal give rise to some Δ^4-androstenedione and dehydroepiandrosterone (see page 751).

The pathways outlined in Figure 15 are largely based on evidence from *in vitro* work with adrenal and testis tissues, but the evidence of in vivo studies in man is consistent with the operation of these pathways. There is an extensive literature on steroid biosynthesis and metabolism in the adrenals and gonads in pathological states, especially in various types of tumours of these tissues and in abnormalities having a genetic basis. The major genetic abnormalities are briefly considered below, but metabolic studies with tumour tissues will not be discussed, though it should be noted that they frequently show abnormal biosynthetic patterns suggested by the symptoms to which the tumours give rise (for instance masculinizing adrenal tumours produce androgens; feminizing tumours produce oestrogens). Since such findings most probably represent an exaggeration of the normal biosynthetic potentialities rather than the addition of totally new features they provide valuable clues to the normal pathways of synthesis.

The C_{21}-steroids of the adrenals can all be derived from cholesterol via 20α-hydroxycholesterol and 20α,22ξ-dihydroxycholesterol. In the adrenals, the first identifiable C_{21}-steroid, pregnenolone, is mostly converted via progesterone into the more highly oxygenated C_{21}-corticoids. A minor pathway for pregnenolone in both the adrenals and testes involves its conversion to 17α-hydroxypregnenolone, which serves as a precursor of the weak androgen dehydroepiandrosterone. The conversion of progesterone into the C_{21}-corticoids takes place mainly by one of two divergent pathways depending upon whether hydroxylation takes place first at the 17α-position (giving 17α-hydroxyprogesterone) or the 21-position (giving deoxycorticosterone). Most of the data indicate that hydroxylation at C-17 proceeds more readily in the absence of the 21-hydroxyl group[7]. Both deoxycorticosterone and 17α-hydroxydeoxycorticosterone may undergo hydroxylation at the 11β-position giving respectively corticosterone and cortisol, which on further oxidation at C-11 yield minor amounts of two further physiologically active substances, 11-dehydrocorticosterone and cortisone. The pathway to aldosterone is still not clear, but its formation from deoxycorticosterone by hydroxylation at C-18 to 18-hydroxycorticosterone and subsequent oxidation has been demonstrated. Other synthetic pathways are also possible[8]. The mechanisms by which aldosterone and cortisol output are controlled (see page 430) are markedly different and in this connection it is probably significant that aldosterone secretion seems to be almost exclusively confined to the outer zone (zona glomerulosa) of the cortex, cortisol secretion to the inner zones.

Further metabolism of C_{21}-steroids and the formation of androgens. The physiologically active corticoids shown in Figure 15 undergo a multiplicity of further transformations, both in the adrenal itself and in other tissues, notably the liver and sex glands. It is not known at present whether these transformations are related to the hormonal function of these compounds. The catabolic reactions may be classified into four principal groups: oxidative degradation, hydroxylation, reduction and conjugation.

Oxidative degradation. The cleavage of the side chain in the C_{21}-steroids having the 17α-hydroxy-20-keto grouping is the main route by which the androgens arise in the testis, ovary and adrenal, as it is in the liver in the course of inactivation of the blood corticoids. It is because this cleavage reaction occurs in the liver that 17-ketosteroid excretion may be taken as a rough index of adrenocortical activity (see page 747). Dehydroepiandrosterone may be formed in the adrenal by cleavage of the side chain of 17-hydroxypregnenolone[9] and possibly of 17α,20α-dihydroxycholesterol. Both these reactions probably occur in the testis also, but the major precursor of testosterone in the testis is progesterone, which is degraded via its 17α-hydroxy derivative. A second possible route from progesterone to testosterone involves its direct oxidation to testosterone acetate. This reaction has been observed microbiologically[10] and there is some evidence for its occurrence in humans.

Hydroxylation[3,4]. Besides the hydroxylations at C-11, C-17, C-18 and C-21 leading to the formation of the active C_{21}-corticoids, the adrenal cortex is also able to hydroxylate steroids of *both* the C_{19}- and C_{21}-series at the 6α-, 6β- and 19-positions. Hydroxylations at C-6 are also known to occur in rat liver, and the guinea-pig adrenal converts cortisol to 2α-hydroxycortisol. Urinary steroids (both

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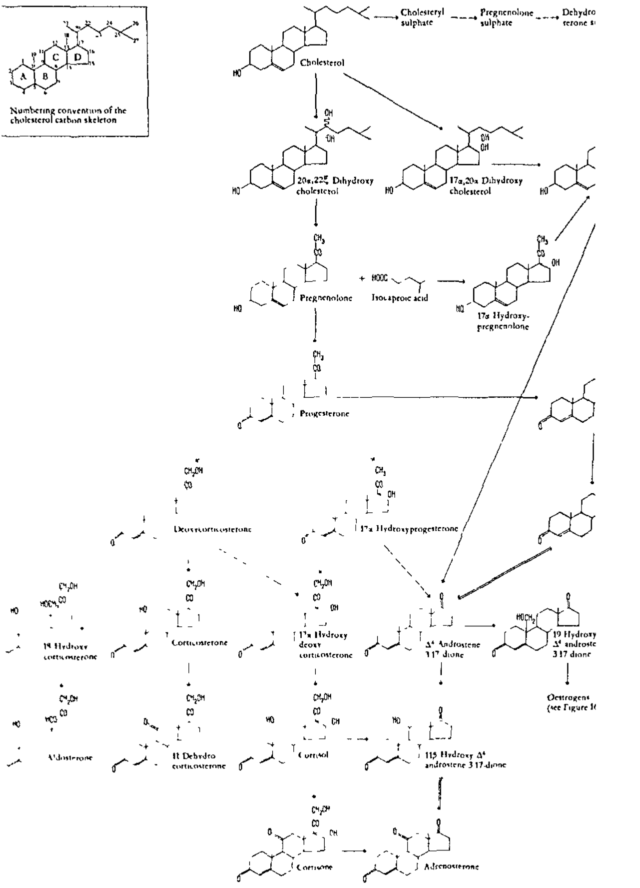
g 15 Biosynthesis of adrenal steroids and androgens



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Biosynthesis and metabolism of steroid hormones of the adrenal cortex and gonads (for references see page 430)

The normal adrenal cortex produces a wider variety of steroid hormones than either the ovary or the testis[1]. Besides producing eight C_{21}-steroids of known structure and proven 'corticoid' activity, it also produces many C_{21}-steroids of unknown physiological activity as well as progesterone, the oestrogens and the androgens of the $C_{19}O_2$- and $C_{19}O_3$-series[2–4]. Adrenal androgen formation[5] is at present more fully documented than the formation of adrenal oestrogens, and the pathway of testicular androgen formation appears to be clearly represented in the adrenal cortex. It is therefore convenient to outline the pathways of androgen synthesis together with the pathways of synthesis of C_{21}-steroids in a single scheme (Fig.15), since these two aspects of steroid metabolism are closely interlinked. The oestrogenic steroids are further transformation products of the androgens and are more conveniently discussed separately (see page 430). The adrenal cortex, the testis, the ovary and the placenta are all capable of synthesizing their characteristic steroid hormones from acetate via cholesterol and pregnenolone, and it seems likely that most of the biosynthetic reactions involved in the synthesis of all classes of steroid hormones are possible in all the above-mentioned organs. However, it is not certain to what extent the hormones secreted normally in vivo are formed from acetate, from blood cholesterol or from steroid precursors synthesized in the adrenal cortex.

The C_{21}-corticoids have profound effects on carbohydrate and protein metabolism ('glucocorticoid' activity) and on sodium and potassium metabolism ('mineralocorticoid' activity). Most of these compounds exert effects of both types with one or the other predominating, according to their chemical structure. The more powerful glucocorticoids are those having oxygen functions at both C-11 and C-17. The glucocorticoid action of the human adrenal is considered to be accounted for almost wholly by the cortisol (hydrocortisone) it produces, since this is both the most potent naturally occurring steroid in this respect and also the most abundant product of the adrenal cortex in man. Corticosterone, the most abundant corticoid of the rat, has a less powerful glucocorticoid action. It is now clear that a portion of the cortisol or corticosterone output of the adrenal is in a protein-bound form in the blood[6]. It seems probable that the unbound portion is to be regarded as the physiologically active form, and various factors (for instance oestrogen levels) affecting the degree of protein-binding of the glucocorticoids may therefore exert important effects on their physiological function. The most potent hormone in the regulation of salt metabolism is aldosterone, a quantitatively minor product. Deoxycorticosterone has a much smaller but still detectable effect on salt metabolism. For further discussion of the adrenocortical steroids see pages 742 sq.

Figure 15 shows the most probable routes of biosynthesis of the physiologically active C_{21}-steroids of the adrenal and depicts the main pathways leading to the androgens testosterone, Δ^4-androstenedione, dehydroepiandrosterone, 11β-hydroxy-Δ^4-androstenedione and Δ^4-androstene-3,11,17-trione (adrenosterone). All these C_{19}-steroids may arise in the adrenal but the last two, having 11-oxygen functions, are probably specifically products of the adrenals. Testosterone is certainly the principal androgen of the testis but probably is formed in only trace amounts in the adrenal. Both the testis and adrenal give rise to some Δ^4-androstenedione and dehydroepiandrosterone (see page 751).

The pathways outlined in Figure 15 are largely based on evidence from *in vitro* work with adrenal and testis tissues, but the evidence of in vivo studies in man is consistent with the operation of these pathways. There is an extensive literature on steroid biosynthesis and metabolism in the adrenals and gonads in pathological states, especially in various types of tumours of these tissues and in abnormalities having a genetic basis. The major genetic abnormalities are briefly considered below, but metabolic studies with tumour tissues will not be discussed, though it should be noted that they frequently show abnormal biosynthetic patterns suggested by the symptoms to which the tumours give rise (for instance masculinizing adrenal tumours produce androgens; feminizing tumours produce oestrogens). Since such findings most probably represent an exaggeration of the normal biosynthetic potentialities rather than the addition of totally new features they provide valuable clues to the normal pathways of synthesis.

The C_{21}-steroids of the adrenals can all be derived from cholesterol via 20α-hydroxycholesterol and 20α,22ξ-dihydroxycholesterol. In the adrenals, the first identifiable C_{21}-steroid, pregnenolone, is mostly converted via progesterone into the more highly oxygenated C_{21}-corticoids. A minor pathway for pregnenolone in both the adrenals and testes involves its conversion to 17α-hydroxypregnenolone, which serves as a precursor of the weak androgen dehydroepiandrosterone. The conversion of progesterone into the C_{21}-corticoids takes place mainly by one of two divergent pathways depending upon whether hydroxylation takes place first at the 17α-position (giving 17α-hydroxyprogesterone) or the 21-position (giving deoxycorticosterone). Most of the data indicate that hydroxylation at C-17 proceeds more readily in the absence of the 21-hydroxyl group[7]. Both deoxycorticosterone and 17α-hydroxydeoxycorticosterone may undergo hydroxylation at the 11β-position giving respectively corticosterone and cortisol, which on further oxidation at C-11 yield minor amounts of two further physiologically active substances, 11-dehydrocorticosterone and cortisone. The pathway to aldosterone is still not clear, but its formation from deoxycorticosterone by hydroxylation at C-18 to 18-hydroxycorticosterone and subsequent oxidation has been demonstrated. Other synthetic pathways are also possible[8]. The mechanisms by which aldosterone and cortisol output are controlled (see page 430) are markedly different and in this connection it is probably significant that aldosterone secretion seems to be almost exclusively confined to the outer zone (zona glomerulosa) of the cortex, cortisol secretion to the inner zones.

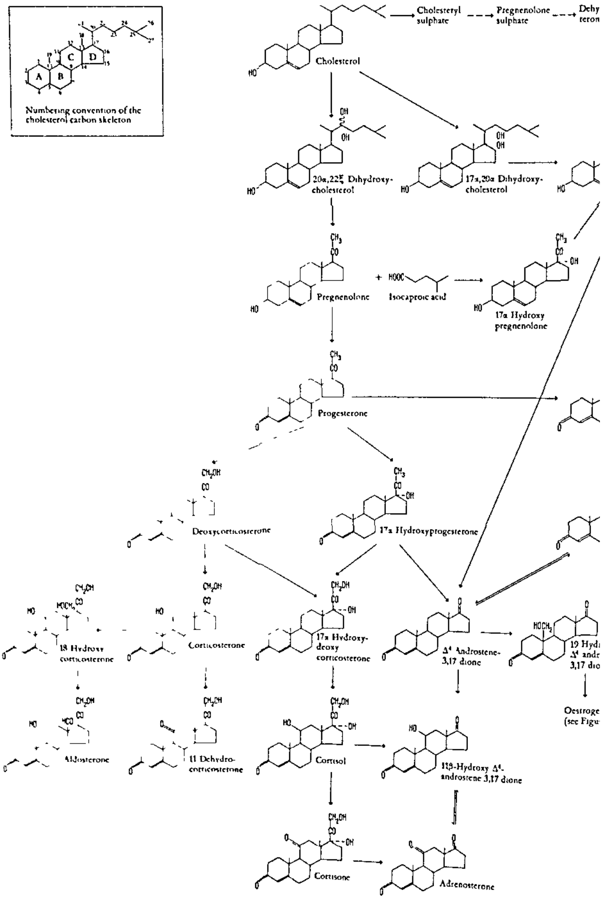
Further metabolism of C_{21}-steroids and the formation of androgens. The physiologically active corticoids shown in Figure 15 undergo a multiplicity of further transformations, both in the adrenal itself and in other tissues, notably the liver and sex glands. It is not known at present whether these transformations are related to the hormonal function of these compounds. The catabolic reactions may be classified into four principal groups: oxidative degradation, hydroxylation, reduction and conjugation.

Oxidative degradation. The cleavage of the side chain in the C_{21}-steroids having the 17α-hydroxy-20-keto grouping is the main route by which the androgens arise in the testis, ovary and adrenal, as it is in the liver in the course of inactivation of the blood corticoids. It is because this cleavage reaction occurs in the liver that 17-ketosteroid excretion may be taken as a rough index of adrenocortical activity (see page 747). Dehydroepiandrosterone may be formed in the adrenal by cleavage of the side chain of 17-hydroxypregnenolone[9] and possibly of 17α,20α-dihydroxycholesterol[5]. Both these reactions probably occur in the testis also, but the major precursor of testosterone in the testis is progesterone, which is degraded via its 17α-hydroxy derivative. A second possible route from progesterone to testosterone involves its direct oxidation to testosterone acetate. This reaction has been observed microbiologically[10] and there is some evidence for its occurrence in humans.

Hydroxylation[3,4]. Besides the hydroxylations at C-11, C-17, C-18 and C-21 leading to the formation of the active C_{21}-corticoids, the adrenal cortex is also able to hydroxylate steroids of both the C_{19}- and C_{21}-series at the 6α-, 6β- and 19-positions. Hydroxylations at C-6 are also known to occur in rat liver, and the guinea-pig adrenal converts cortisol to 2α-hydroxycortisol. Urinary steroids (both

(continued on page 430)

Fig 15 Biosynthesis of adrenal steroids and androgens



C_{19}- and C_{21}-) with 16α-hydroxy groups have also been isolated, and hog adrenal tissue is able to carry out hydroxylations at this position.

Reduction. In general, the body tends to eliminate steroid hormones in the form of metabolites in which the Δ^4-3-keto system of ring A is totally reduced (Fig.15). Theoretically, this reduction may lead to products having either 3α- or 3β-hydroxy groups and the hydrogen atom at C-5 in either the 5α- or 5β-configuration. Actually, almost all reduced metabolites excreted by man are of the 3α-hydroxy-5β- (C_{21}: pregnane; C_{19}: aetiocholane) series. Minor quantities of steroids of the 3α-hydroxy-5α-(C_{21}: allopregnane; C_{19}: androstane) series are also excreted. Metabolism of steroid hormones by tissues of other species, in particular rat liver (*in vitro*) yields predominantly (but not exclusively) reduction products of the 5α-series having both 3α- and 3β-hydroxy groups. Reduction of the Δ^4-3-keto moiety apparently proceeds in stepwise fashion, the Δ^4-bond being reduced first[11]. Interesting sex differences have been observed in the intracellular distribution and overall concentration of Δ^5-steroid reductases in the rat[12].

Conversion of the 20-keto group to a 20-hydroxy group is a further important catabolic reduction of the C_{21}-steroids and also follows a course in most *in vitro* tissue preparations sterically different from that found in man. The product *in vitro* is generally a 20β-hydroxy derivative; that excreted by man is almost exclusively a 20α-hydroxy derivative.

Conjugation and excretion. The steroid excretion products of the urine are present largely in the form of conjugates with glucuronic acid or with sulphate. Dehydroepiandrosterone and androsterone are present in the urine to a major extent as sulphate conjugates. There is evidence for the secretion of some dehydroepiandrosterone as the sulphate[13]. Some of this material may arise via a series of intermediates derived directly from cholesteryl sulphate[14], but the quantitative importance of this pathway remains to be established. Cortisone and cortisol are apparently excreted in the urine largely in the free form, but the majority of the C_{21}-metabolites are excreted as β-glucuronides; the latter appear to arise primarily in the liver by a mechanism involving glucuronosyl transfer from uridine diphosphate glucuronic acid[15]. It has been demonstrated that about 50% of the blood cortisol is in the glucuronide form[16].

Pituitary control. The adrenal cortex is maintained in a normal functional state by the action of pituitary ACTH. Apart from this generalized influence on the metabolism of adrenal cortical tissue, ACTH also exerts a specific and immediate stimulating effect on the process of corticosteroid biogenesis. The precise point (or points) at which this influence is exerted is still in doubt. One important point of action is considered to be at a very early stage, probably in the conversion of cholesterol to pregnenolone[17]. It has also been observed that ACTH stimulation can alter the ratio of the amounts of cortisol and corticosterone secreted, but such an effect does not necessarily imply intervention of ACTH in the later stages of biosynthesis[18]. The mechanism of action of ACTH remains largely unknown at the present time despite intensive study[19]. For further discussion of this subject see page 717.

Aldosterone. Aldosterone, the steroid hormone mainly responsible for controlling electrolyte balance, is unique in that it has an aldehydic group at C-18 and is synthesized in the zona glomerulosa of the cortex. Aldosterone production has been demonstrated from a number of precursors but the major route is probably progesterone → deoxycorticosterone → corticosterone → aldosterone (Fig.15). The major metabolic product seems to be tetrahydroaldosterone glucuronide[20]. The 18-hydroxytetrahydrocorticosterone found in human urine is a metabolite of 18-hydroxycorticosterone and not of aldosterone[21].

Since aldosterone output falls by only 30% after hypophysectomy ACTH would appear to have little effect on aldosterone secretion[22]. More important and more direct is probably the regulation by the sodium and potassium concentrations and the extracellular fluid volume of the body. Angiotensin also plays an important part[23] (see page 741).

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Biosynthesis and metabolism of oestrogens

(For references see page 432)

It is now evident that all the tissues active in the synthesis of steroid hormones are capable of some degree of oestrogen synthesis. Under more usual physiological conditions the ovaries are certainly the most active site of such synthesis, but their output is surpassed several hundred-fold by the placenta close to term.

The oestrogens are C_{18}-steroids in which ring A is aromatic, and there is now ample evidence for the biosynthesis[1,2] of these compounds from acetate via cholesterol, pregnenolone, progesterone and the C_{19}-steroids, according to the scheme outlined in Figure 16. The aromatization of ring A evidently takes place via a C_{19}-steroid intermediate in which the C-19 methyl group has been oxidized, though whether this intermediate has a hydroxylic or aldehydic oxygen function at C-19 has not been unequivocally established. The C-19 atom is released as formaldehyde[3], a finding interpreted as indicating that oxidation at C-19 proceeds to the aldehyde stage prior to rupture of the C-10 to C-19 bond, as shown. Several other mechanisms could, however, yield the same end products. There is evidence that the aromatizing enzyme system has rather low specificity with respect to the structure of the molecule as a whole. Thus, both 6α- and 6β-hydroxy-Δ^4-androstene-3,17-dione are converted to the corresponding 6-hydroxyoestrogens[4].

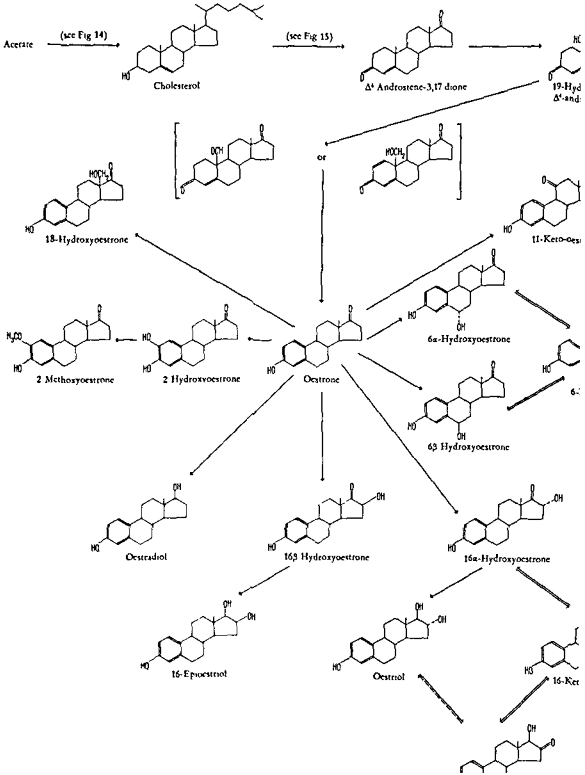
Intermediary metabolism of oestrogens

When radioactive oestrone or oestradiol-17β is administered to intact animals or incubated with animal tissues the oestrogenic activity is rapidly destroyed; considerably less than half of the administered radioactivity can be recovered in the ether-soluble fraction even after hydrolysis of the excreta or the incubation mixture with acid or with enzymes which release the oestrogens from their known conjugated forms[1,5]. The nature of the oestrogen derivatives that resist extraction with ether in such experiments is entirely unknown, and this fact should not be overlooked when considering the significance of the work relating to oestrogen metabolism summarized in the following sections.

When either oestradiol or oestrone is injected into a human subject, conjugates of the three steroids oestriol, oestrone and oestradiol-17β appear in the urine in the approximate proportions 45:45:10. The relative constancy of these proportions indicates a rapid equilibration of oestrone and oestradiol in the body tissues. The enzyme responsible for the interconversion in the human placenta has been studied extensively. It can utilize either NAD or NADP as cofactor, a finding that has prompted speculation as to the mode of physiological action of the oestrogenic hormones[6].

During the past few years, several other phenolic steroids besides the 'classical' oestrogens – oestradiol, oestrone and oestriol – have been isolated from various sources and have been characterized chemically. Thus it is now clear that hydroxylation of oestrone may occur at the 2-, 6-, 11-, 16- or 18-position. The interrelationships of these various compounds are shown in Figure 16. Hydroxylation at the 2-position is followed by methylation. Both reactions occur in the liver, and both 2-hydroxy- and 2-methoxyoestrone may be eliminated in the urine. The methylation reaction is catalyzed by an O-methyl transferase which, like other O-methyl trans-

Fig. 16 Biosynthesis and metabolism of oestrogens



16α-hydroxyoestrone[9]. Very small amounts of 17-epioestriol are also formed. 16β-Hydroxyoestrone is a further product, but on enzymic reduction gives 16-epioestriol with 16,17-epioestriol as a minor product. 18-Hydroxyoestrone occurs in pregnancy urine[10] and there is evidence that this compound is of adrenal origin[11].

Equilin and equilenin are well known as urinary oestrogens of the pregnant mare, and equilenin has been identified as a metabolite of a feminizing adrenal tumour in man[12]. Evidence against the derivation of these compounds from oestrone has been put forward, but since it is based on *in vivo* work with horses it must be accepted with reservation.

Conjugates of oestrogen metabolites. The urinary oestrogens are excreted predominantly in the form of conjugates with glucuronic acid or sulphate. Oestriol is converted to both the 16- and 17-glucuronosides, but the involvement of the phenolic oxygen function in glucuronoside formation has definitely been established in the case of oestrone. This steroid accepts the glucuronic acid residue from UDP-glucuronic acid in a typical reaction catalysed by a glucuronyl transferase[1]. The formation of the sulphates involves the phenolic hydroxyl function in the case of oestriol and oestrone. The mechanism of this reaction has not been described, but the mechanism of formation of other sulphate esters has been extensively studied[13].

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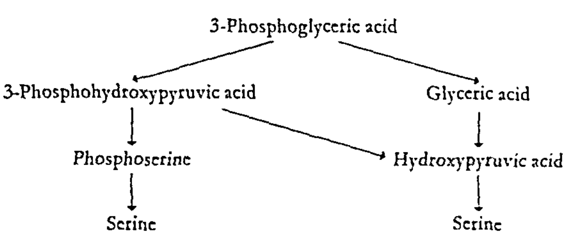
Formation of serine and glycine

Serine can be formed from glucose via phosphoglyceric acid. It is not certain at what stage the phosphate is removed from the ester link and the evidence is in accordance with several possibilities[1] as follows:



Glycine is formed from serine by the action of serine hydroxymethyltransferase, the hydroxymethyl group being transferred to tetrahydrofolic acid to form hydroxymethyltetrahydrofolic acid[2]:

$$\text{serine} + \text{THF} \rightleftharpoons \text{glycine} + \text{THF–CH}_2\text{OH}$$

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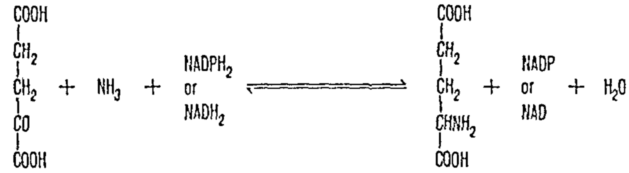
Formation of glutamic acid

Glutamic acid is readily synthesized in liver and other animal tissues when α-ketoglutarate, ammonia and reduced NAD or NADP are available. The reaction is catalysed by glutamate dehydrogenase:

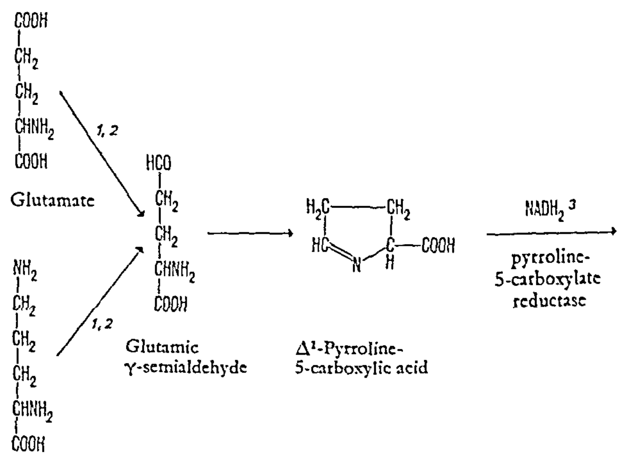


α-Keto-glutaric acid L-Glutamic acid

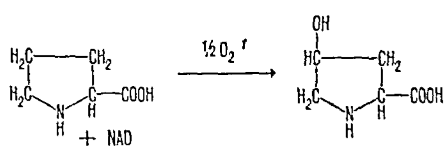
Glutamic acid is the only amino acid in animal tissues that can be directly synthesized from ammonia and the corresponding carbon skeleton (supplied in the form of the α-ketonic acid). All other nonessential amino acids are formed from the corresponding α-ketonic acids by transamination with glutamate. The reductive amination of α-ketoglutarate is thus the most important ammonia-binding reaction in the animal body.

Formation of proline and hydroxyproline

These amino acids are assumed to be formed from ornithine or glutamic acid via glutamic semialdehyde according to the following sequence of reactions:



Glutamate, Ornithine, Glutamic γ-semialdehyde, Δ^1-Pyrroline-5-carboxylic acid



Proline Hydroxyproline

Collagen hydroxyproline is derived from proline by hydroxylation of prolyl residues in a precursor polypeptide, the so-called protocollagen[4]. In an analogous reaction hydroxylysine is derived from peptide-linked lysine[5].

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Formation of histidine

The capacity of man to synthesize histidine has not been established. In micro-organisms this amino acid is synthesized from ATP, ribose 5-phosphate 1-pyrophosphate and glutamine in a ten-stage reaction[1].

Reference
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Metabolism – Synthesis of Cell Constituents from Amino Acids

(For references see page 436)

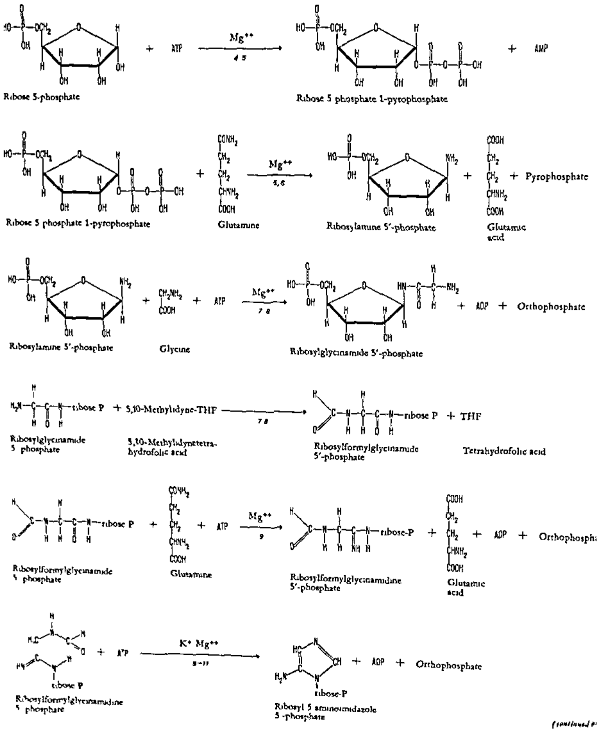
ynthesis of cell constituents from amino acids

The principal products, their pathways of formation and their hysiological functions are summarized in Table 20 on page 434

ormation of purines

Knowledge of the pathways shown below and on pages 435 and 36 is derived mainly from ... The substrates utilized in this process include glutamine, glycine, ...

Formation of inosinic acid (inosine monophosphate, IMP)



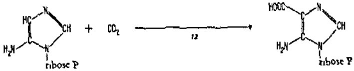
(continued o

Table 20 Formation of basic cell constituents and metabolites from amino acids
This list is not comprehensive; for carbohydrate synthesis from amino acids see page 441.

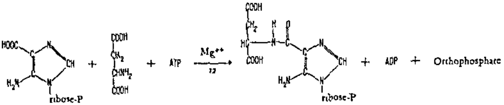
Amino acid serving as starting material	Product formed	Pathway of formation	Physiological function
Glycine	Purine bases	See page 433	Constituent of nucleic acids and nucleotides
	Porphyrins	See page 437	Constituent of haemoglobin and cytochromes
	Creatine	See page 437	Precursor of creatine phosphate, an energy store muscle and other tissues
	Glutathione	See page 438	Coenzyme function in the glyoxalase system and i cis-trans isomerases and probably other enzymes
	Hippuric acid and related compounds	See page 445	Detoxication product of benzoic acid
	Bile acids	See page 438	Required for digestion of fats
Serine	Ethanolamine	Decarboxylation (see Table 6, page 394)	Constituent of phospholipids
	Choline	Methylation of ethanolamine, methionine acting as a methyl group donor	Constituent of phospholipids
	Acetylcholine	Acetylation of choline by acetyl-coenzyme A[1]	Transmitter substance at nerve endings
Cysteine	Taurine	See page 438	Constituent of bile acids
	Glutathione	See page 438	See above under 'Glycine'
Glutamic acid	Glutamine	From glutamic acid and ammonia in the presence of ATP[2]	Cell constituent. Intermediate carrier of amino groups in aminations and amidations
	γ-Aminobutyric acid	Decarboxylation (see Table 6, page 394)	Cell constituent, especially of brain
	Glutathione	See page 438	See above under 'Glycine'
	Proline	See page 432	Protein constituent
	Hydroxyproline	See page 432	Protein constituent
Arginine	Creatine	See page 437	See above under 'Glycine'
Methionine	Creatine	See page 437	See above under 'Glycine'
	Choline	Decarboxylation (see Table 6, page 394)	See above under 'Serine'
Histidine	Histamine	Decarboxylation (see Table 6, page 394)	Vasodilator. Stimulates gastric secretion
Aspartic acid	Pyrimidine bases	See page 439	Constituent of nucleic acids and nucleotides
	β-Alanine	Probably by α-decarboxylation	Constituent of special peptides (anserine, carnosine, coenzyme A, pantothenic acid)
Tyrosine	Adrenaline	See page 440	Hormone
	Noradrenaline	See page 440	Hormone and transmitter substance at nerve endings
	Thyroxine	See page 440	Hormone
	Melanins	See page 440	General pigments of hair and skin
Tryptophan	5-Hydroxytrypt-amine (serotonin)	See page 441	Transmitter substance at nerve endings in the CNS
	Nicotinic acid	See page 399 and 476	Constituent of nicotinamide-adenine dinucleotides
Glucogenic amino acids	Carbohydrates	See page 441	

References [1] Korkes et al., *J. biol. Chem.*, 198, 215 (1952). [2] Elliott, W.H., *J. biol. Chem.*, 201, 661 (1953).

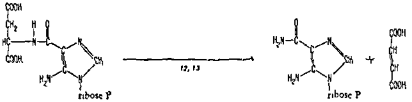
Metabolism – Synthesis of Cell Constituents from Amino Acids



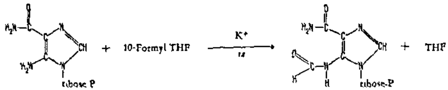
Ribosyl-5-aminoimidazole 5'-phosphate — Ribosyl-5-amino-4-carboxy-imidazole 5'-phosphate



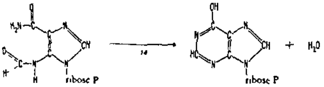
Ribosyl-5-amino-4 carboxyimidazole 5'-phosphate — Aspartic acid — Ribosyl-5 amino-4 succino-carboxamidoimidazole 5'-phosphate



Ribosyl 5-amino-4 succinocarboxamido-imidazole 5'-phosphate — Ribosyl-5 amino-4-carboxamido-imidazole 5'-phosphate — Fumaric acid

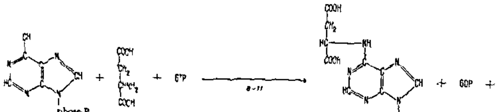


Ribosyl 5-amino-4 carboxamido imidazole 5' phosphate — Formyltetra hydrofolic acid — Ribosyl-5-formamido-4 carboxamido-imidazole 5'-phosphate — Tetrahydrofolic acid

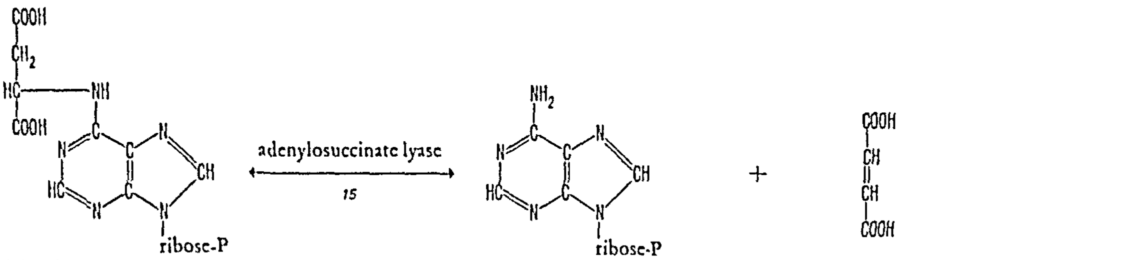


Ribosyl 5 formamido-4-carboxamido-imidazole 5 phosphate — Inosinic acid

Formation of adenylic acid (adenosine monophosphate, AMP)

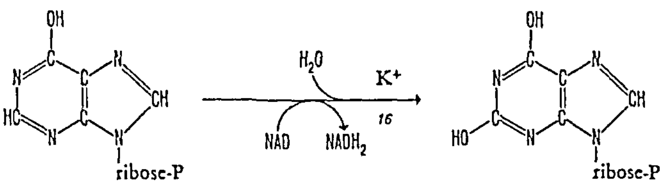


Inosinic acid — Aspartic acid — Adenylosuccinic acid (N succinyladenylic acid)



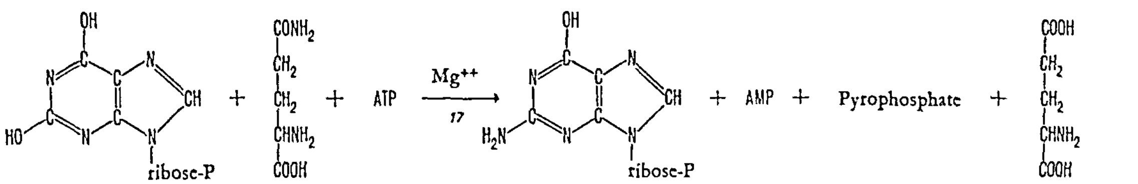
Adenylosuccinic acid (*N*-succinyladenylic acid) — Adenylic acid — Fumaric acid (13)

Formation of xanthylic acid (xanthosine monophosphate, XMP)



Inosinic acid — Xanthylic acid (14)

Formation of guanylic acid (guanosine monophosphate, GMP)



Xanthylic acid — Glutamine — Guanylic acid — Glutamic acid (15)

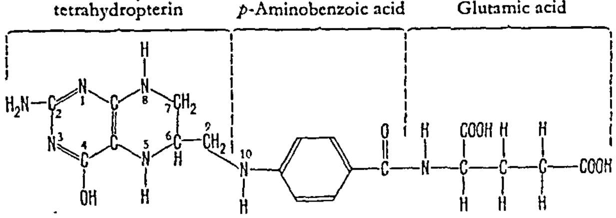
References

[1] Carter, C.E., *Ann. Rev. Biochem.*, **25**, 123 (1956); Buchanan and Hartman, *Advanc. Enzymol.*, **21**, 199 (1959); Hartman and Buchanan, *Ann. Rev. Biochem.*, **28**, 365 (1959).
[2] Kornberg et al., *J. biol. Chem.*, **215**, 417 (1955).
[3] Christman, A.A., *Physiol. Rev.*, **32**, 303 (1952).
[4] Kornberg et al., *J. biol. Chem.*, **215**, 389 (1955).
[5] Goldthwait et al., *Biochim. biophys. Acta (Amst.)*, **18**, 148 (1955).
[6] Goldthwait, D.A., *J. biol. Chem.*, **222**, 1051 (1956).
[7] Goldthwait et al., *J. biol. Chem.*, **221**, 569 (1956); Warren and Buchanan, *J. biol. Chem.*, **229**, 613 (1957).
[8] Hartman et al., *J. biol. Chem.*, **221**, 1057 (1956).
[9] Levenberg and Buchanan, *J. biol. Chem.*, **224**, 1005 and 1019 (1957).
[10] Melnick and Buchanan, *J. biol. Chem.*, **225**, 157 (1957).
[11] Goldthwait et al., in McElroy and Glass (Eds.), *A Symposium on Amino Acid Metabolism*, Johns Hopkins Press, Baltimore, 1955, page 765; Buchanan et al., in McElroy and Glass (Eds.), *A Symposium on Amino Acid Metabolism*, Johns Hopkins Press, Baltimore, 1955, page 743.
[12] Miller and Buchanan, *J. biol. Chem.*, **237**, 485 (1962).
[13] Miller et al., *J. Amer. chem. Soc.*, **79**, 1513 (1957).
[14] Flaks et al., *J. biol. Chem.*, **229**, 603 (1957).
[15] Lieberman, I., *J. biol. Chem.*, **223**, 327 (1956).
[16] Carter and Cohen, *J. biol. Chem.*, **222**, 17 (1956).
[17] Abrams and Bentley, *Arch. Biochem.*, **58**, 109 (1955); Lagerkvist, U., *Acta chem. scand.*, **9**, 1028 (1955); Gehring and Magasanik, *J. Amer. chem. Soc.*, **77**, 4685 (1955).

Transfer of groups containing one carbon atom [1]

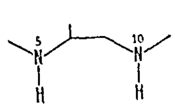
Tetrahydrofolic acid (THF) is the coenzyme of many reactions involving the transfer of a group containing one carbon atom. In most cases the one-carbon fragment is attached to nitrogen atoms 5 or 10 of THF, or to both.

2-Amino-4-hydroxy-6-methyl-tetrahydropterin — *p*-Aminobenzoic acid — Glutamic acid

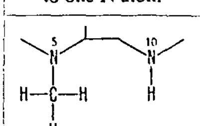
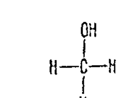
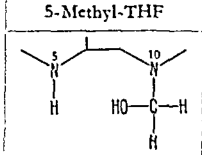
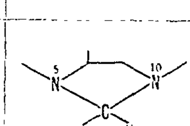
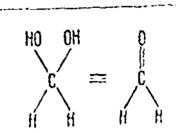
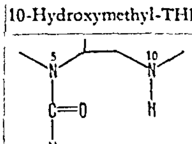
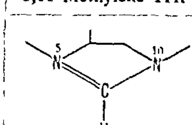
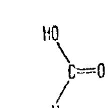
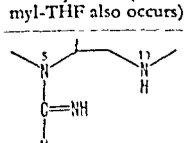
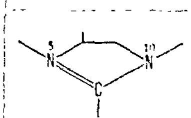
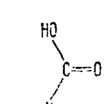


Tetrahydrofolic acid

For the sake of brevity it is common to draw only the portion of the THF molecule that includes these atoms:



The groups most commonly transferred and their mode of attachment to THF are as follows:

Group attached to one N atom	Group attached to two N atoms	Oxidation state equivalent to
 5-Methyl-THF		 Methanol
 10-Hydroxymethyl-THF	 5,10-Methylene-THF	 Formaldehyde
 5-Formyl-THF (10-formyl-THF also occurs)	 5,10-Methylidyne-THF	 Formic acid
 5-Formimino-THF	 5,10-Methylidyne-THF	 Formic acid

Formyl-THF, hydroxymethyl-THF and methyl-THF are enzy-atically interconvertible. The reactions are catalysed by specific xidoreductases[1]

$$\text{5,10-methylidyne-THF} + \text{NADPH} \rightleftharpoons \text{5,10-methylene-THF} + \text{NADP} \quad (1)$$

$$\text{5,10-methylene-THF} + \frac{\text{NADPH}}{(\text{NADH})} \rightleftharpoons \text{5-methyl-THF} + \frac{\text{NADP}}{(\text{NAD})} \quad (2)$$

... to 5,10-methylidyne-THF by reac- ... lidyne- ... formed ... minor importance.

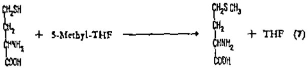
$$\text{5-formyl-THF} + \text{ATP} \rightarrow \text{5,10-methylidyne-THF} + \text{ADP} + \text{orthophosphate} \quad (3)$$

$$\text{10-formyl-THF} \rightarrow \text{5,10-methylidyne-THF} + H_2O \quad (4)$$

$$\text{formate} + \text{ATP} + \text{THF} \rightarrow \text{10-formyl-THF} + \text{ADP} + \text{orthophosphate} \quad (5)$$

$$\text{DHF} + \text{NADPH}_2 \rightarrow \text{THF} + \text{NADP} \quad (6)$$

Another important methylation reaction is the formation of methionine from homocysteine (7). Vitamin B_{12} is involved in this reaction.



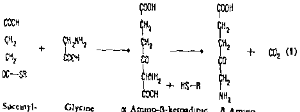
Homocysteine — Methionine

References

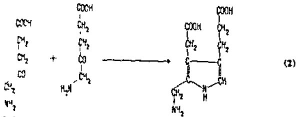
[1] GREENBERG, D. M., *Advanc. Enzymol.*, 25, 395 (1963); HUENNEKENS, F. M., *Biochemistry*, 2, 151 (1963).

Formation of porphyrins

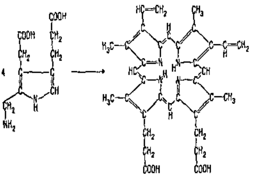
... cine[1]. The formation of this complex molecule has been demonstrated to proceed via δ-aminolaevulinic acid and porphobilinogen[2] by the following reactions:



Succinyl-coenzyme A (see page 390) — Glycine — α-Amino-β-ketoadipic acid (hypothetical intermediate) — δ-Aminolaevulinic acid



δ-Aminolaevulinic acid (2 molecules) — Porphobilinogen

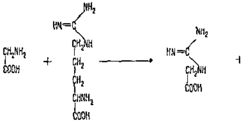


Porphobilinogen — Protoporphyrin IX

References

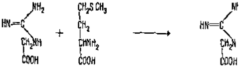
Formation of creatine from glycine, arginine and

Creatine (which in the form of creatine phosph... store of 'phosphate bond energy') is formed by tw... tions. The basic skeleton of creatine is provided by... first transfer reaction the group HN=C–NH₂ is tr... arginine to glycine.



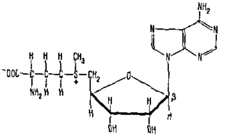
Glycine — Arginine — Guanidinoacetic acid (glycocyamine)

In the second reaction the methyl group of meth... ferred to the guanidinoacetic acid formed in the fi...



Guanidino-acetic acid — Methionine — Creat...

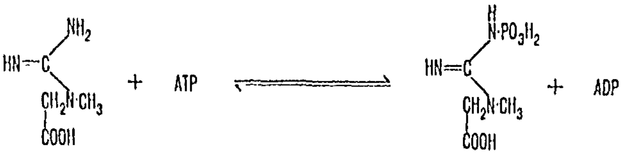
Methionine does not react as the free amino ac... adenosyl derivative, formed from ATP and methi...



S-Adenosylmethionine

Homocysteine appears likewise as the adenosyl ... transmethylation reaction formulated above.[3]

Creatine interacts reversibly with ATP, especial... form creatine phosphate.



Creatine — Creatine phosphate

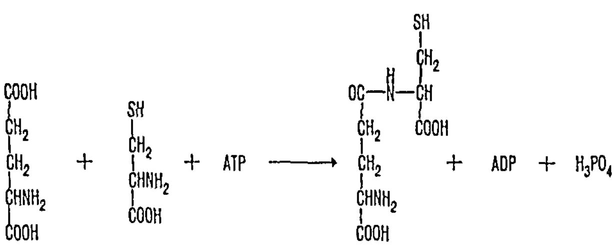
The reaction proceeds from left to right in resting muscle, and from right to left during prolonged contractions, regenerating ATP spent as an energy source in the process of contraction.

References

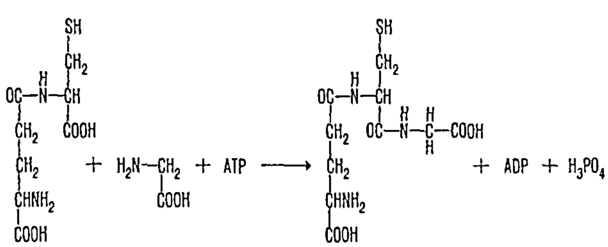
[1] For a review see Arnstein, H.R.V., *Advanc. Protein Chem.*, 9, 1 (1954).
[2] Cantoni, G.L., *J. biol. Chem.*, 204, 403 (1953); Cantoni and Scarano, *J. Amer. chem. Soc.*, 76, 4744 (1954); Cantoni and Vignos, *J. biol. Chem.*, 209, 647 (1954); Mudd and Cantoni, *J. biol. Chem.*, 231, 481 (1958).
[3] Cantoni and Scarano, *J. Amer. chem. Soc.*, 76, 4744 (1954).

Formation of glutathione

Glutathione is formed in two main steps that have been demonstrated to occur in the liver. The first of these involves the formation of the dipeptide γ-L-glutamyl-L-cysteine from glutamic acid, cysteine and ATP[1]. This is followed by the formation of glutathione itself from γ-L-glutamyl-L-cysteine, glycine and ATP[2]:



L-Glutamic acid — L-Cysteine — γ-L-Glutamyl-L-cysteine



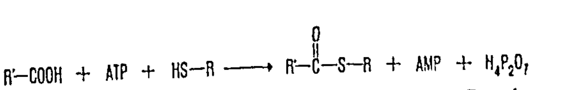
γ-L-Glutamyl-L-cysteine — Glycine — Glutathione

References

[1] Mandeles and Bloch, *J. biol. Chem.*, 214, 639 (1955).
[2] Snoke, J.E., *J. biol. Chem.*, 213, 813 (1955).

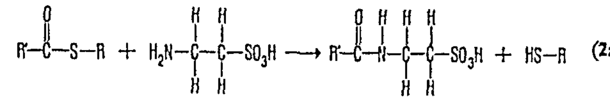
Formation of bile acid conjugates[1]

Bile acids such as cholic and deoxycholic acids are excreted into the intestine in the form of glycine or taurine conjugates. The major factor controlling the ratios of glycine and taurine conjugates appears to be the availability of taurine. The specificity and activity of the enzyme systems are such as to favour the formation of taurine conjugates[2]. The reactions require the presence of coenzyme A and ATP, and presumably proceed by a mechanism similar to that involved in the activation of acetate (page 391) and aromatic acids (page 444)[3]:



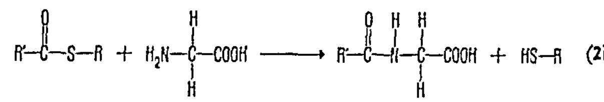
(1)

Bile acid — Coenzyme A — Bile acyl-coenzyme A — Pyrophosphoric acid



(2a)

Bile acyl-coenzyme A — Taurine — Bile acid-taurine conjugate (e.g., taurocholic acid) — Coenzyme A



(2b)

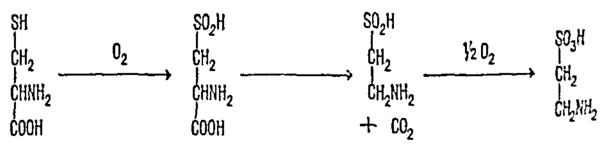
Bile acyl-coenzyme A — Glycine — Bile acid-glycine conjugate (e.g., glycocholic acid) — Coenzyme A

References

[1] Bergström and Borgström, *Ann. Rev. Biochem.*, 25, 187 (1956).
[2] Bremer, J., *Acta chem. scand.*, 9, 268 (1955).
[3] Bremer, J., *Acta chem. scand.*, 9, 1036 (1955); Pihl et al., *J. biol. Chem.*, 227, 339 (1957); Elliott, W.H., *Biochem. J.*, 62, 427, 433 (1955); 65, 315 (1957).

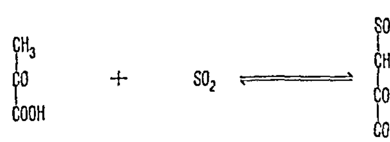
Formation of taurine

Taurine is formed from cysteine in the liver and possibly in other organs. The pathway in mammalian tissues is via cysteinesulphinic acid and hypotaurine[1]:

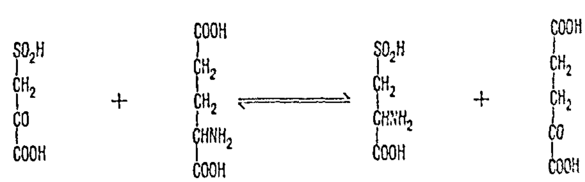


Cysteine — Cysteinesulphinic acid — Hypotaurine — Taurine

Cysteinesulphinic acid may also be formed from pyruvic acid, sulphur dioxide and glutamic acid by the following reactions[2]:



Pyruvic acid — β-Sulphinylpyruvic acid



β-Sulphinyl-pyruvic acid — Glutamic acid — Cysteine-sulphinic acid — α-Keto-glutaric acid

References

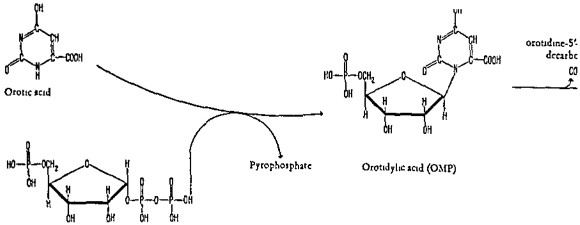
[1] Awapara and Wingo, *J. biol. Chem.*, 203, 189 (1953); Cavallini et al., *J. biol. Chem.*, 216, 577 (1955); Hope, B.D., *Biochem. J.*, 59, 497 (1955); Bergeret et al., *Biochim. biophys. Acta (Amst.)*, 17, 128 (1955); Chapeville and Fromageot, *Biochim. biophys. Acta (Amst.)*, 17, 275 (1955).
[2] Chapeville and Fromageot, *Biochim. biophys. Acta (Amst.)*, 14, 415 (1954).

Formation of pyrimidines

The starting materials of pyrimidine synthesis are aspartic acid and carbamyl phosphate. The pathway shown below occurs in mammals[1] and bacteria[2]. Orotic acid is the first complete pyrimidine to be formed. This is converted to orotidylic acid (OMP)[3] and then to uridylic acid (UMP), cytidylic acid[4] and thymidylic acid* (TMP)[5].

* Strictly speaking, this compound should be termed deoxythymidylic acid (dTMP) since it contains deoxyribose.

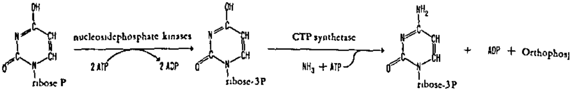
Aspartic acid Carbam (see p



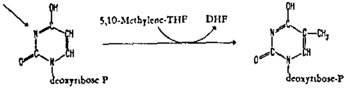
Orotic acid

Orotidylic acid (OMP)

Ribose 5 phosphate 1 pyrophosphate*



Uridylic acid (UMP) Uridine triphosphate (UTP) Cytidine triphosphate (CTP)



Deoxyuridylic acid Thymidylic acid**

* This compound is formed by reaction (1), page 433

** Strictly speaking, this compound should be termed deoxythymidylic acid (dTMP) since it contains deoxyribose

References

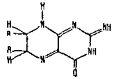
[1] CARTER, C.E., *Ann Rev Biochem*, 25, 123 (1956) LOWENSTEIN and COHEN, *J biol Chem*, 220, 57 (1956), COOPER et al., *J biol Chem*, 216, 37 (1955)

Conversion of phenylalanine to tyrosine

The enzymic conversion of phenylalanine to tyrosine involves a pteridine cofactor The reaction can be considered to proceed in two parts The first consists of a hydroxylation involving molecu- ... of 4-hydroxytetrahydropteridine[1]

	4-hydroxytetrahydropteridine + phenylalanine + O_2	→ 4 hydroxydihydropteridine + tyrosine + H_2O	(1)
	4-hydroxydihydropteridine + $NADPH_2$	→ 4-hydroxytetrahydropteridine + NADP	(2)
Sum	phenylalanine + O_2 + $NADPH_2$	→ tyrosine + H_2O + NADP	(3)

A possible form of 4 hyd...



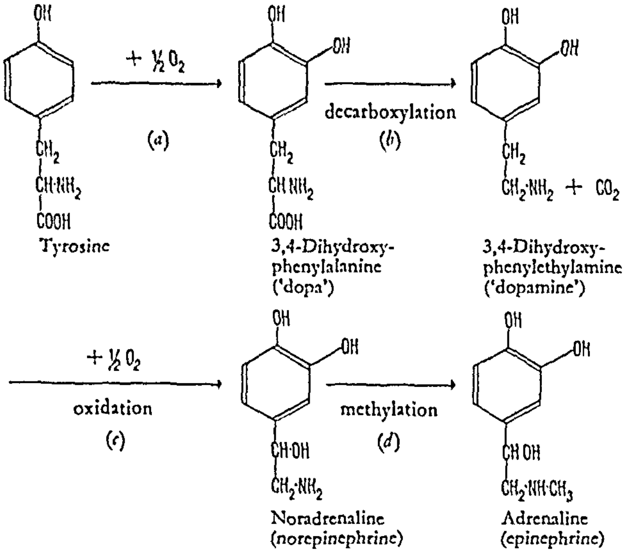
4 Hydroxydihydropteridine ('para quinonoid' form)

Reference

[1] KAUFMAN, S., *J biol Chem*, 239, 332 (1964)

Formation of noradrenaline and adrenaline from tyrosine

Noradrenaline and adrenaline are formed from tyrosine (and thus from phenylalanine), the main pathway being as follows[1]:



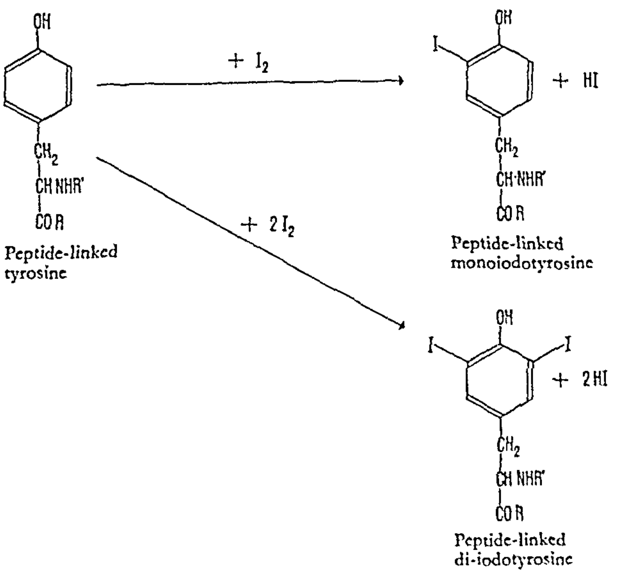
Enzymes
(*a*) tyrosine hydroxylase
(*b*) dopa decarboxylase
(*c*) dopamine hydroxylase
(*d*) phenylethanolamine *N*-methyltransferase

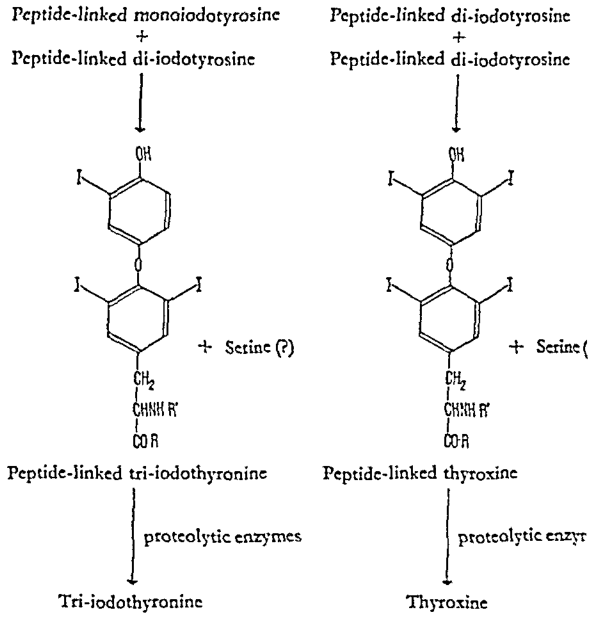
The reaction catalysed by tyrosine hydroxylase is probably the rate-limiting step[2]. The enzyme phenylethanolamine *N*-methyltransferase is found almost exclusively in the adrenal gland[3].
Alternative pathways have been proposed[4].

References
[1] For a review see Blaschko, H., *Pharmacol. Rev.*, 11, 307 (1959).
[2] Levitt et al., *Pharmacol. exp. Ther.*, 198, 1 (1965).
[3] Axelrod, J., *J. biol. Chem.*, 237, 1657 (1962).
[4] Axelrod, J., *Science*, 190, 499 (1963); Kopin, I.J., *Z. klin. Chem.*, 2, 115 (1964); Iversen, L.L., *Nature*, 219, 8 (1967).

Formation of thyroid hormones[1]

Iodide is absorbed in the gastrointestinal tract and rapidly distributed in the extracellular fluid. Except during the postprandial period the iodide concentration of plasma is less than 5 µg/l. This inorganic iodide of the plasma is removed almost entirely by the kidneys and thyroid gland. The concentration of readily exchangeable iodine in the normal thyroid in terms of whole tissue or of tissue water may be 20-40 or more times greater than that in the plasma. Prior to the iodination of the tyrosine molecule the iodide





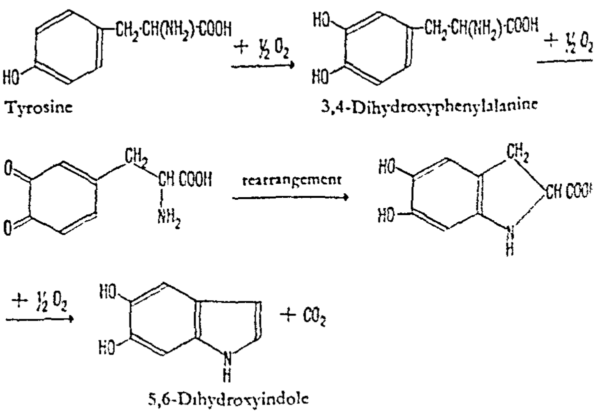
must be oxidized to free iodine or the iodinium ion, a reacti probably involving a peroxidase. The iodination of tyrosine monoiodotyrosine and di-iodotyrosine probably takes place peptide-linked tyrosyl residues. The thyroid hormones tri-iod thyronine and thyroxine are formed by condensation of iodotyr syl residues, the side chain of one tyrosyl residue giving rise serine in this coupling reaction.

Tri-iodothyronine and thyroxine are retained in the thyro within the colloid as peptide-linked residues in the specific pr tein thyroglobulin. The thyroid hormones are released from tl thyroglobulin pool by enzymatic hydrolysis as required. The fu ther metabolism of these hormones is described on pages 726-72

References
[1] For a review see Roche and Michel, *Physiol Rev.*, 35, 583 (1955); Roc et al., in Florkin and Mason (Eds.), *Comparative Biochemistry*, vol 5, Ac demic Press, New York, 1963, page 514; Stanbury, J.B., in Stanbury et (Eds.), *The Metabolic Basis of Inherited Disease*, 2nd ed., McGraw-Hill, Ne York, 1966, page 215.

Formation of melanin from tyrosine[1]

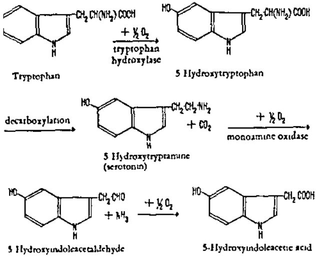
Melanin is the pigment of vertebrate skin, hair, feathers and eye (see page 722). It is a complex and nonhomogeneous substance The chief basic unit is 5,6-dihydroxyindole, which undergoes poly merization and in the polymerized form combines with protein[2]. It is formed from tyrosine, probably by the following route (thi route is blocked in albinism; cf. page 448):



References
[1] For a review see Mason, H.S., *Advanc. Enzymol.*, 16, 163 (1955); Dalgliesh, C.E., *Advanc. Protein Chem.*, 10, 65 (1955).
[2] Cromartie and Harley-Mason, *Biochem. J.*, 66, 713 (1957).

ormation and degradation of 5-hydroxytryptamine erotonin)

5-Hydroxytryptamine (serotonin) is assumed to be a neurotransmittor substance in the CNS, it may play a role in haemostasis, in



The reaction catalysed by the enzyme tryptophan hydroxylase is probably the rate-limiting step in the synthesis of serotonin[4]

Serotonin is the precursor of melatonin in the pineal gland (see page 730)

References

[1] Erspamer V., *Pharmacol Rev*, 6, 425 (1954) Spector and Willoughby, *Nature*, 179, 318 (1957), Page, I H., *Physiol Rev*, 38, 277 (1958)

[2] Page et al, *Lancet*, 1, 198 (1955), Pernow and Waldenström, *Lancet*, 2, 951 (1954)

1962, page 324

[4] Jequier et al, *Molec Pharmacol*, 3, 274 (1967)

Synthesis of carbohydrate from amino acids and other non-carbohydrate precursors (gluconeogenesis)

amino to yield pyruvate (or phosphopyruvate). The pathway from pyruvate to glucose includes most steps of the anaerobic glycolysis (Table 3, page 389) in reverse, but at three stages special reactions occur[1] circumventing the energy barriers which would prevent a simple reversal of glycolysis.

(*a*) The formation of phosphopyruvate from pyruvate The special reactions by which phosphopyruvate is formed are[2]

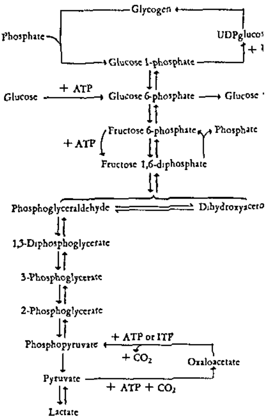
$$\text{pyruvate} + ATP + CO_2 \xrightarrow{\text{pyruvate carboxylase}} \text{oxaloacetate} + ADP + \text{phosphate}$$

$$\text{oxaloacetate} + ATP \text{ or } ITP \xrightarrow{\text{phosphopyruvate carboxylase}} \text{phosphopyruvate} + ADP \text{ or } IDP$$

(*b*) Fructose 1,6-diphosphate is converted into fructose 6-phosphate by a specific phosphatase[3] (and not by transfer of phosphate to ADP)

Fig 17 Pathways of carbohydrate breakdown and syn

The pathways differ at four points Breakdown reac dicated by the left hand arrows, synthesis reactions b hand arrows



$$\text{fructose } 1,6\text{-diphosphate} \xrightarrow{\text{hexosediphosphatase}} \text{fructo } 6\text{-pho} + \text{phc}$$

(*c*) Glucose 6-phosphate is likewise dephosphorylated b phosphatase[4] (and not by transfer to ADP)

$$\text{glucose } 6\text{-phosphate} \xrightarrow{\text{glucose 6 phosphatase}} \text{gluco} + \text{phc}$$

(*d*) Glucose 1-phosphate is converted into glycogen glucose[5] and not by reversal of the phosphorylase

$$\text{glucose } 1\text{-phosphate} + UTP \xrightarrow{\text{glucose-1 phosphate uridylyltransferase}} \text{UDP-} + \text{pyr}$$

$$\text{UDP-glucose} + \text{glycogen}_n \xrightarrow{\text{UDPglucose glycogen glucosyltransferase}} \text{glyco} + \text{UE}$$

The stages of carbohydrate synthesis from pyruvate rized in Figure 17 above

References

Detoxication mechanisms

A number of metabolic processes do not fall under the headings of either energy supply or synthesis of cell constituents. Their common feature is the disposal of potentially harmful substances. In other words they contribute towards the maintenance of the physiological environment. These metabolic processes are commonly referred to as 'detoxication mechanisms'.

Quantitatively the most important detoxication mechanism is the conversion of surplus nitrogen, in particular surplus ammonium ions, into urea (see below). Other detoxication reactions concern the disposal of certain ingested materials (e.g., benzoic acid) and of drugs. A recent review of drug metabolism can be found in GOLDSTEIN et al.[1]

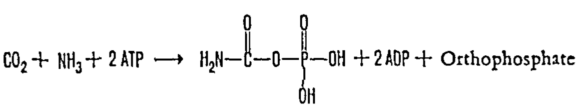
Reference

[1] GOLDSTEIN et al., *Principles of Drug Action*, Harper & Row, New York, 1968.

Synthesis of urea[1] (for references see page 444)

Most of the surplus nitrogen arising in the mammalian body is excreted in the form of urea. The synthesis of urea from ammonia and carbon dioxide proceeds by a cyclical mechanism. The concept of the urea (or ornithine) cycle was originally based on the observation that *ornithine, citrulline and arginine stimulate urea production in the presence of ammonia without being themselves consumed in the process*[2]. Since it was proposed, this concept has received support from many other experiments[1]. The reactions of the cycle involve the stepwise building-up of the urea structure on the δ-amino group of ornithine. The building-up process is completed with the formation of arginine, which is then hydrolysed by arginase to yield urea and ornithine.

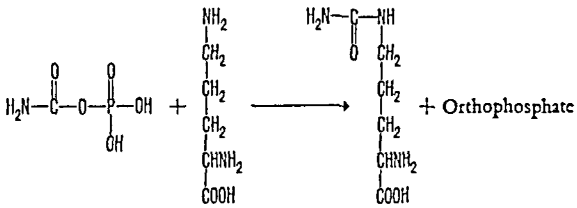
Before one molecule each of ammonia and carbon dioxide enter the cycle, they react to form carbamyl phosphate. The synthesis of this compound requires ATP and has been formulated as follows[3,4]:



(1)

Carbamyl phosphate

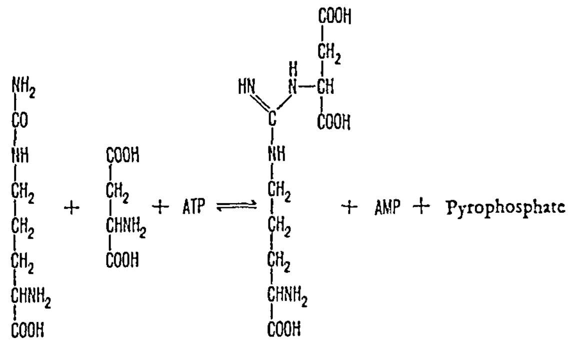
Reaction (1) is stimulated by acetylglutamate and by other acy glutamates[5]. It is probable that acetylglutamate is the compoun normally involved *since it occurs in mammalian liver*[6]. In bacteri the stimulation by acetylglutamate does not occur, and only on molecule of ATP is utilized per molecule of carbamyl phosphat formed. The nature of the action of acetylglutamate is obscur Carbamyl phosphate reacts with ornithine to yield citrulline[3,7]



(2

Carbamyl phosphate Ornithine Citrulline

Citrulline next condenses with aspartic acid to form argininosuccinic acid[8], a process that requires ATP:

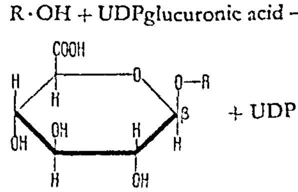


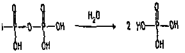
(3)

Citrulline Aspartic acid Argininosuccinic acid

Reaction (3) is freely reversible, but under physiological conditions it proceeds only from left to right because of the presence of a highly active pyrophosphatase[9]:

Table 21 Detoxication mechanisms

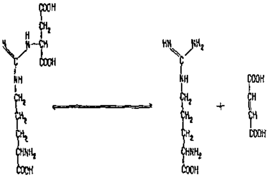
Reaction	Examples of compounds detoxicated	Product formed	Mechanism
Acetylation	Sulphanilamide	Acetylsulphanilamide	See page 444
Methylation	Nicotinamide	*N*-Methylnicotinamide	The methyl group is derived from methionine probably via *S*-adenosylmethionine (see page 437)
Glycine conjugation	Benzoic acid	Hippuric acid	See page 444
Alkyl- and arylglucuronide formation	Alcohols and phenols (menthol and phenol)	Menthyl- and phenyl-glucuronide	R·OH + UDPglucuronic acid →  β-Glucuronide
Acylglucuronide formation	Aromatic acids (benzoic acid) and branched-chain aliphatic acids	Benzoylglucuronide	Not known
Sulphate ester formation	Phenols	Phenyl sulphate	See page 445
Glutamine conjugation	Phenylacetic acid	Phenacetylglutamine	See page 445
Mercapturic acid formation	Naphthalene, alkyl halides	Naphthylmercapturic acid	See page 445



(4)

Pyrophosphoric acid Orthophosphoric acid

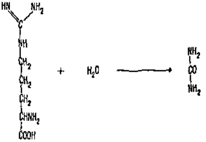
Argininosuccinate reacts further to give arginine and fumarate[10] by reaction (5):



(5)

Argininosuccinic acid Arginine Fumaric acid

This is followed by the hydrolysis of argin
urea. Ornithine can then undergo the same se
starting with reaction (2):

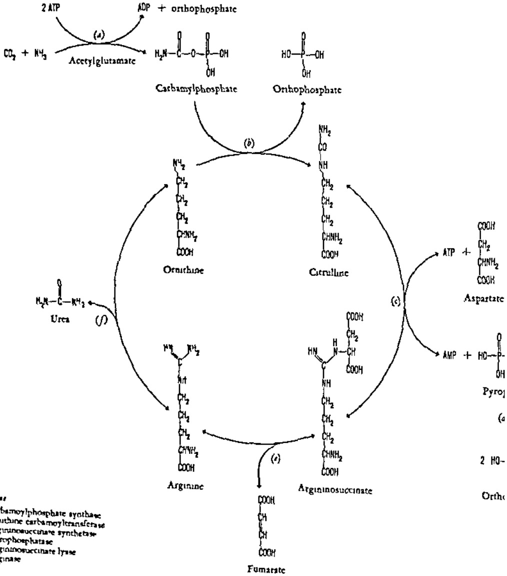


Arginine Urea

The cyclic sequence of the reactions

Fig 18 The urea cycle (ornithine cycle)

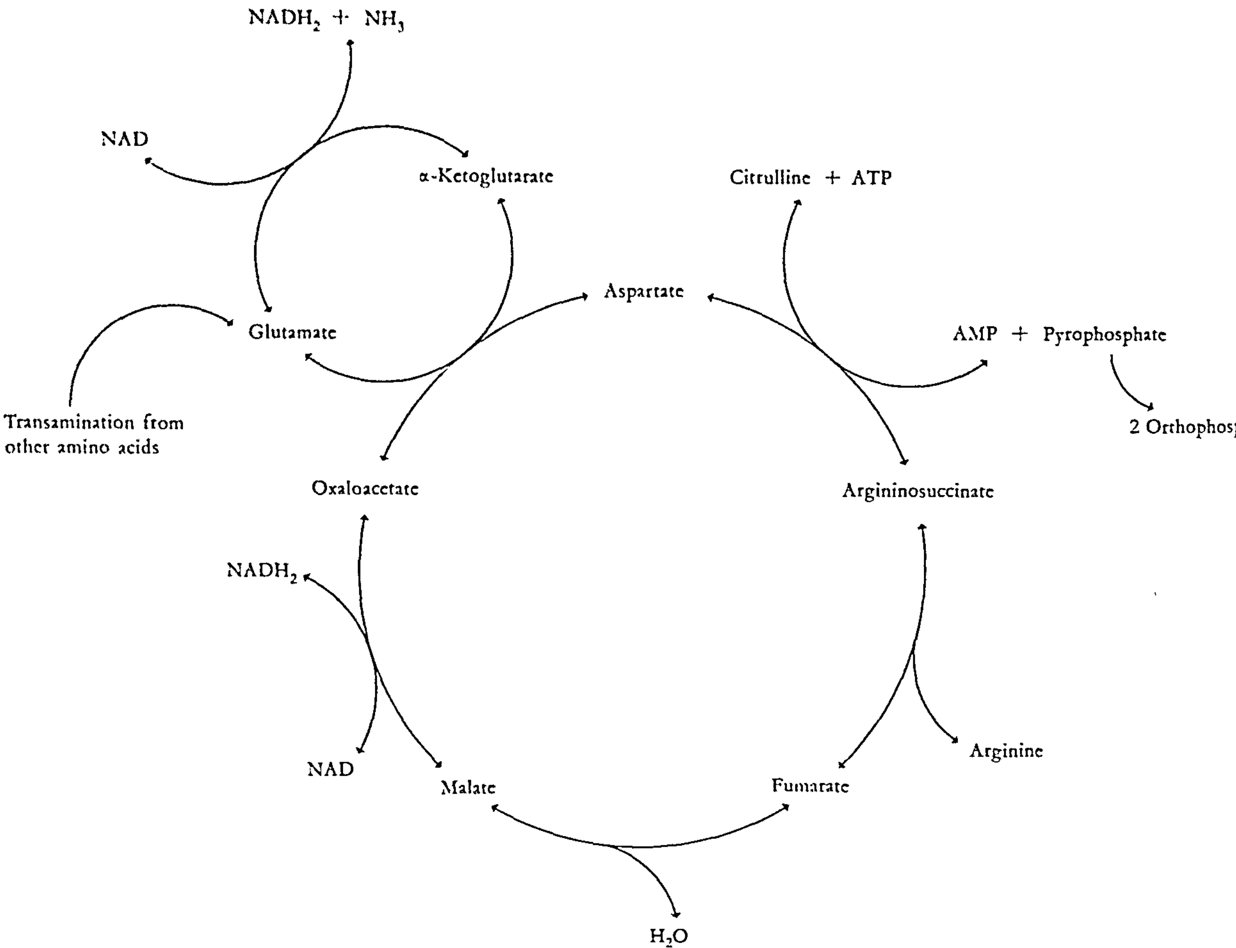
A list of the enzymes involved in the cycle is given below the diagram



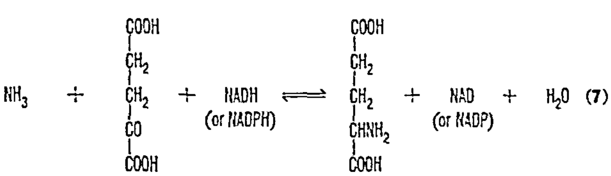
Enzymes

(a) carbamoylphosphate synthase
(b) ornithine carbamoyltransferase
(c) argininosuccinate synthetase
(d) pyrophosphatase
(e) argininosuccinate lyase
(f) arginase

Fig. 19 Utilization and regeneration of aspartate in the synthesis of urea



and α-ketoglutarate (see page 393) or by reductive amination from ammonia and α-ketoglutarate[11]:



Ammonia α-Ketoglutaric acid Glutamic acid

The second nitrogen atom of urea must thus pass through glutamate and aspartate but not necessarily through the stage of ammonia. The supply of aspartate for reaction (3) involves two cycles, which are subsidiary to the main urea cycle shown in Figure 18. These subsidiary processes are shown in Figure 19, above.

References

1 For reviews see Krebs, H.A., in Sumner and Myrbäck (Eds.), *The Enzymes*, vol. 2, part 2, Academic Press, New York, 1952, page 866; Ratner, S., *Advanc. Enzymol.*, 15, 319 (1954); Cohen and Brown, in Florkin and Mason (Eds.), *Comparative Biochemistry*, vol. 2, Academic Press, New York, 1960, page 161; Cohen and Sallach, in Greenberg, D.M. (Ed.), *Metabolic Pathways*, Academic Press, New York, 1961, page 1.
2 Krebs and Henseleit, *Hoppe-Seyl. Z. physiol. Chem.*, 210, 33 (1932).
3 Jones et al., *J. Amer. chem. Soc.*, 77, 819 (1955).
4 Metzenberg et al., *J. biol. Chem.*, 229, 1019 (1957).
5 Grisolia and Cohen, *J. biol. Chem.*, 204, 753 (1953).
6 Hall et al., *Nature*, 178, 1468 (1956); Hall et al., *J. biol. Chem.*, 230, 1013 (1958).
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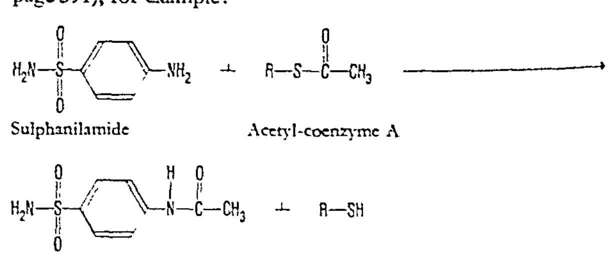
8 Ratner et al., *J. biol. Chem.*, 204, 95 (1953).
9 Ratner and Petrack, *Arch. Biochem.*, 65, 582 (1956).
10 Ratner et al., *J. biol. Chem.*, 204, 115 (1953).
11 Olson and Anfinsen, *J. biol. Chem.*, 202, 841 (1953).

Acetylation of amines[1]

Many aromatic and aliphatic amines are acetylated in the body. These include sulphanilamide, *p*-aminobenzoic acid, *p*-nitraniline and others[2]. In general, the acetylated amines are less toxic than the unacetylated compounds. However, in some cases the low solubility of acetylated amines can render them harmful owing to their crystallization in the urinary tract.

The acetylation reaction proceeds via acetyl-coenzyme A (see page 391), for example:



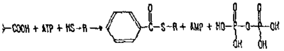
References

1 Tabor et al., *J. biol. Chem.*, 204, 127 (1953); Lipmann, F., *Bact. Rev.*, 17, 1 (1953).
2 Williams, R.T., *Detoxication Mechanisms*, 2nd ed., Chapman & Hall, London, 1959; Williams, R.T., *Clin. Pharmacol. Ther.*, 4, 234 (1963).

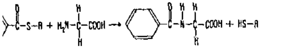
Formation of glycine conjugates

Aromatic acids such as benzoic acid, nicotinic acid, cinnamic acid and similar compounds are conjugated with glycine in various organs[1]. The reaction requires coenzyme A and ATP, and pro-

y a mechanism similar to that involved in the activation of (see page 391), for example:



acid — Coenzyme A — Benzoyl-coenzyme A — Pyrophosphoric acid



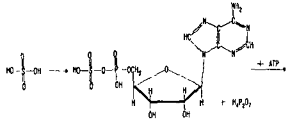
l-coenzyme A — Glycine — Hippuric acid — Coenzyme A

nces

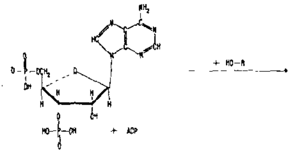
ITRENNE, H, *J biol Chem*, 189, 227 (1951), SCHACHTER and TAGGART, *Chem*, 208, 263 (1954); MOLDAVE and MEISTER, *J biol Chem*, 229, 1957)

ation of esters of sulphuric acid

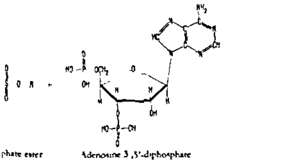
urally occurring sulphate esters include the polysaccharides



Adenosine 5' phosphosulphate — Pyrophosphoric acid



nosine 3' phosphate 5 phosphosulphate



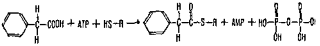
phate ester — Adenosine 3,5'-diphosphate

ferences

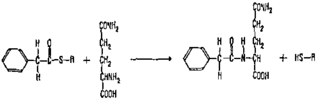
WILLIAMS, R T, *Detoxication Mechanisms*, 2nd ed, Chapman & Hall, London, 959

ANDURSKI et al, *J Amer chem Soc*, 78, 6408 (1956), ROBBINS and LIPMANN, *Amer chem Soc*, 78, 2652, 6409 (1956), ROBBINS and LIPMANN, *J biol Chem*, 29, 837 (1957), GREGORY and LIPMANN, *J biol Chem*, 229, 1081 (1957)

Formation of phenacetylglutamine



Phenylacetic acid — Coenzyme A — Phenylacetyl-coenzyme A — Pyrophosphoric acid



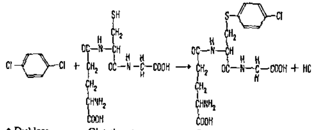
Phenylacetyl-coenzyme A — Glutamine — Phenylacetyl-glutamine — Coenzyme A

The first of these reactions occurs in beef as well as human

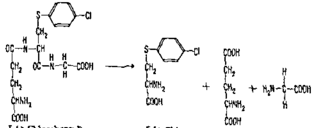
of the latter on incubating phenylacetic acid on ATP has not been demonstrated

Formation of mercapturic acids

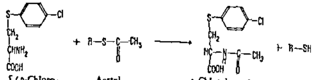
A number of aromatic compounds (e g, halogenobenzenes, naphthalene) give rise on ingestion to mercapturic acids (*N*-acetyl-*S*-arylcysteines)[1] The mechanism of formation of these compounds is as follows[2]



p-Dichlorobenzene — Glutathione — *S*-(*p*-Chlorobenzyl)-glutathione



S (*p*-Chlorobenzyl)-glutathione — *S*-(*p* Chlorobenzyl)cysteine — Glutamic acid — Glycine



S (*p*-Chlorobenzyl)-cysteine — Acetyl-coenzyme A — *p*-Chlorobenzyl mercapturic acid (*N*-acetyl-*S*-*p*-chlorobenzylcysteine) — Coenzyme A

References

[1] WILLIAMS, R T, *Detoxication Mechanisms*, 2nd ed, Chapman & Hall, London, 1959

[2] BRAY et al, *Biochem J*, 71, 690 (1959), BOOTH et al, *Biochem J*, 79, 516 (1961)

Inborn Errors of Metabolism *

Introduction

A number of diseases are now known to be caused by a failure of the body to synthesize sufficient quantities of one specific protein, often an enzyme, or by the synthesis of an abnormal protein in place of the normal one. Failure to synthesize an enzyme can cause a complete or partial block of a metabolic pathway and usually leads to the accumulation of the intermediary metabolite that is normally the substrate of the missing enzyme. In some cases the accumulation of this metabolite leads to abnormal side reactions. In phenylketonuria, for example, absence of phenylalanine 4-hydroxylase leads to accumulation of phenylalanine, some of which is converted to phenylpyruvic acid, and this undergoes further changes to *o*-hydroxyphenylacetic acid, phenyl-lactic acid and phenylacetylglutamine.

In some cases the defective protein is not an enzyme in the narrower sense, i.e., a catalyst bringing about a chemical change, but a substance concerned with the active transport of a metabolite from one compartment of the body to another. Examples are intestinal absorption and renal tubular reabsorption. In such cases the resulting disease or abnormality is not caused by a metabolic block but by a disturbance of transportation and the secondary effects of this disturbance. In Hartnup disease, for example, tryptophan is poorly absorbed from the intestine and is in consequence acted on by bacteria in the colon to produce abnormal indo compounds that are absorbed. In this disease there is also a rer tubular defect leading to amino-aciduria.

These defects in the synthesis of an enzyme or transport mech nism are genetically determined and are referred to as inborn errc of metabolism. Some defects of this kind consisting of sing enzyme failures can be acquired, like the action of a heavy me poison on proximal renal tubular transport of amino acids and hexachlorobenzene on porphyrin metabolism or the production alkaptonuria in experimental animals by administration of α, dipyridyl. Such acquired defects are often temporary.

Some gene mutations lead to the formation of an abnorm structural protein rather than the absence of an enzyme. Th clearest examples are the haemoglobinopathies, where the stru ture of some of the abnormal proteins has been completely eluc dated. In the thalassaemias there is a relative failure to synthesiz haemoglobin rather than production of an abnormal haemoglobi Thalassaemia is thought to be caused by mutation of a 'controlle or 'tap' gene, abnormal haemoglobins by mutations of 'structura genes. Inborn errors of metabolism may resemble either type c haemoglobinopathy: mutation of the relevant structural gene woul produce in place of the normal enzyme a protein lacking catalyti properties, while a 'silent gene' mutation would produce neither th enzyme nor an abnormal protein.

Haemoglobinopathies [1]

Four major types of haemoglobin occur in normal erythrocytes: Hb-A_1 (or A), Hb-A_2, Hb-F and Hb-A_3. In the adult, Hb-A_1 constitutes over 85% of the normal haemoglobin and Hb-A_2 about 2½%. Hb-F is the major constituent in utero but is rarely detectable after the first year of extrauterine life. Hb-A_3 is a compound of Hb-A_1 and glutathione found in older erythrocytes and will not be further considered.

Each molecule of haemoglobin consists of four polypeptide chains of two different types and four haem groups. Hb-A_1 has two α^A and two β^A polypeptide chains; Hb-A_1 can be formulated as $\alpha_2^A\beta_2^A$, Hb-A_2 as $\alpha_2^A\delta_2^{A_2}$ and Hb-F as $\alpha_2^A\gamma_2^F$. The synthesis of each type of polypeptide chain, α, β, γ or δ, is controlled by a different pair of genes. Each polypeptide consists of between 140 and 150 amino-acid residues. The identity of the amino-acid residue at any point on the chain is determined by the structure of the triplet of deoxyribonucleotides at the corresponding point on the DNA chain constituting the gene. A change in this triplet (i.e., a mutation) may alter the identity of the amino acid incorporated at this point in the chain and thus produce a different polypeptide. Combination of this abnormal polypeptide with other polypeptide chains and haem groups produces an abnormal haemoglobin.

Over 100 different abnormal haemoglobins are known, each produced by a mutation affecting one type of polypeptide chain. In sickle-cell anaemia, for example, the β gene has undergone mutation to produce an abnormal β polypeptide (β^S) with valine in place of glutamic acid at position 6, but the α gene is normal. The major haemoglobin produced by the homozygote is therefore $\alpha_2^A\beta_2^S$, accompanied by normal $\alpha_2^A\gamma_2^F$ and $\alpha_2^A\delta_2^{A_2}$; the heterozygote has $\alpha_2^A\beta_2^A$ as well.

Hydrolysis of haemoglobin or its separated polypeptides with trypsin breaks up the chains wherever a lysine or arginine residue occurs, producing a series of oligopeptides. These can be separated by paper electrophoresis and chromatography to produce a two-dimensional pattern of peptides characteristic of the starting protein, a so-called 'fingerprint'. In an abnormal haemoglobin one tryptic peptide in general will differ from its normal counterpart in one of the constituent amino acids and hence in its position (and possibly reactions) on the 'fingerprint'. The relevant peptide spot can be cut out and further analysed.

An abnormal haemoglobin is first denoted by a letter or geographical location or by both, for example Hb-S, Hb-Norfolk, Hb-D_{Punjab}. When it is known which polypeptide chain is abnormal the nomenclature is modified, for example Hb-S $= \alpha_2^A\beta_2^S$, Hb-Norfolk $= \alpha_2^{Norfolk}\beta_2^A$. The tryptic peptides of the α chain are numbered αTp I to αTp XIV, those of the β chain βTp I to βTp XV; if known, the tryptic peptide containing the changed amino-acid residue is indicated, for example Hb-S $= \alpha_2^A\beta_2^S = \alpha_2^A\beta_2^{Tp\,I}$; Hb-Norfolk $= \alpha_2^{Norfolk}\beta_2^A = \alpha_2^{Tp\,VII}\beta_2^A$. The alteration in amino-acid composition, when known, is indicated by, for example, Hb-S $= \alpha_2^A\beta_2^{Tp\,I(Glu\rightarrow Val)}$, Hb-Norfolk $= \alpha_2^{Tp\,VII(Gly\rightarrow Asp)}\beta_2^A$. Finally, when the structure is completely elucidated, the notation used gives the amino acid substituted for the normal one in Hb-A and the position in the polypeptide at which the substitution occurs, for example, Hb-S $= \alpha_2^A\beta_2^{6Val}$, Hb-Norfolk $= \alpha_2^{57Asp}\beta_2^A$. A similar notation applies to the γ and δ chains, though as yet few abnormalities of these have been described.

The thalassaemias are a group of genetically determined anaemias in which the production of α chains, β chains or β + δ chains is greatly decreased or absent. Each type of thalassaemia is carried by a single autosomal gene with heterozygote expression and more marked homozygote expression.

Where α, β or δ chains are produced they are normal in structure; the various thalassaemias are probably caused by mutations of 'tap' genes controlling the activity of the α, β or β + δ structural genes respectively. If α chains are not made, Hb-A_1, Hb-A_2 and Hb-F cannot be formed. Homozygotes for α-thalassaemia probably all die in utero, while heterozygotes have more or less severe anaemia. Since surplus β, γ and δ chains are produced, α-thalassaemics sometimes possess abnormal haemoglobins with four β chains (Hb-H), four γ chains (Hb-Bart's) and, probably, four δ chains. In β-thalassaemia no abnormal haemoglobins are present but Hb-A_1 is decreased in amount or completely absent. In a pure β-thalassaemia, Hb-A_2 is increased in amount, as is Hb-F, but in thalassaemias where the activity of both β and δ genes is reduced, Hb-A_2 as well as Hb-A_1 is decreased in amount. Except in the High Hb-F condition, all homozygotes for β-thalassaemia and 95% of heterozygotes for α- or β-thalassaemia exhibit morphological abnormalities of the erythrocytes in the form of hypochromia, poikilocytosis, frequent target cells and microcythaemia. The erythrocytes show decreased osmotic fragility. The anaemia is caused both by reduced formation of the globin moiety of haemoglobin and by haemolysis.

Thalassaemias are classified on clinical grounds. Probably all homozygotes for β-thalassaemia have thalassaemia 'major', and the majority of heterozygotes thalassaemia 'minor', 'minima' or 'trait'. There is some overlapping, however, as with heterozygotes for α-thalassaemia, who may show any degree of anaemia from very mild to very severe.

The High Hb-F gene is classified with the thalassaemias since it suppresses formation of β and δ chains. However, it is clinically harmless even when combined with sickle-cell trait in double heterozygotes. The High Hb-F condition has been called 'nonmicrocythaemic thalassaemia' [2].

Hb-Lepore and related diseases in homozygous form closely resemble the β-thalassaemias clinically as well as in the morphology of the erythrocytes and in the high proportion of Hb-F in the blood. In the Hb-Lepore group, however, an abnormal haemoglobin is present in place of Hb-A_1 and Hb-A_2. This abnormal haemoglobin has normal α chains but in place of β or δ chains a hybrid of these two. These abnormal β/δ polypeptides are formed

* This chapter on 'Inborn Errors of Metabolism' has been written in collaboration with L. I. Woolf (Department of the Regius Professor of Medicine, Radcliffe Infirmary, Oxford).

probably by nonhomologous crossings over of the β and δ genes, which are adjacent[3].

Although most abnormal haemoglobins are found only very rarely, the genes for thalassaemia (Hb-S, Hb-C and Hb-E) occur with high frequency in some parts of the world. Some of these,

be found for the markedly uneven geographical distribution of the genes for Hb-C and Hb-E

Some representative haemoglobinopathies are listed in Table 1

References

Table 1 Haemoglobinopathies and thalassaemias

Condition or abnormal haemoglobin	Haemoglobins present		Clinical features	Original geographical distribution
Sickle-cell anaemia	$\alpha_2^A\beta_2^{6\,Val}$ (Hb-S) $\alpha_2^A\delta_2^{A_2}$ (Hb-A_2) $\alpha_2^A\gamma_2^F$ (Hb-F)	77–87% 2 5% 10–20%	Infarcts and haemolytic anaemia	Central and West Africa, India, South Arabia, Mediterranean lands
Sickle-cell trait (heterozygotes for above)	$\alpha_2^A\beta_2^A$ (Hb-A_1) $\alpha_2^A\beta_2^{6\,Val}$ (Hb-S)	56–76% 20–40%	Usually symptomless, sickling crises if anoxic	As above
Hb-C disease	$\alpha_2^A\beta_2^{6\,Lys}$ $\alpha_2^A\delta_2^{A_2}$ $\alpha_2^A\gamma_2^F$	88% 9% 2%	Fairly mild haemolytic anaemia, splenomegaly	Northern Ghana
Hb-SC disease (heterozygote for Hb-S and Hb-C)	$\alpha_2^A\beta_2^{6\,Val}$ $\alpha_2^A\beta_2^{6\,Lys}$ $\alpha_2^A\gamma_2^F$	52 5% 43 5% 3 5%	Severe haemolytic anaemia	Parts of Ghana and neighbouring countries
Hb-E	$\alpha_2^A\beta_2^{26\,Lys}$		Relatively mild anaemia	Thailand, South-east Asia
Hb-$G_{San\,Jose}$	$\alpha_2^A\beta_2^{7\,Gly}$		Symptomless	–
Hb-M group (at least 5 different types)	Hb-M_{Boston} $= \alpha_2^{Tp\,VII\,(His \to Tyr)}\beta_2^A$		Methaemoglobinaemia, fairly severe anaemia	Europe (?)
Hb-Zurich	$\alpha_2^A\beta_2^{63\,Arg}$		Sulphonamides produce haemolytic crises	Europe (?)
Hb-Lepore (at least 3 forms Hb-$Lepore_{Boston}$ Hb-$Lepore_{Hollandia}$ Hb-Pylos)	Hb-Lepore $\alpha_2^A\gamma_2^F$	25% 75%	As in β-thalassaemia	–
δ Thalassaemia	$\alpha_2^A\delta_2^{A_2}$	reduced (none in homozygotes)	None, unless combined with β- or (δβ)-thalassaemia	Greece
(δβ)-Thalassaemia (F thalassaemia)	$\alpha_2^A\beta_2^A$ $\alpha_2^A\delta_2^{A_2}$ $\alpha_2^A\gamma_2^F$	none or reduced none or reduced up to 100% in homozygotes 5–15% in heterozygotes	As for β thalassaemia	Greece, Central Africa

Table 1 (continued) Haemoglobinopathies and thalassaemias

Condition or abnormal haemoglobin	Haemoglobins present		Clinical features	Original geographical distribution
β-Chain thalassaemia (Cooley's anaemia, Mediterranean anaemia, thalassaemia major, A_2-thalassaemia, etc.)	$\alpha_2^A\beta_2^A$ $\alpha_2^A\gamma_2^F$ $\alpha_2^A\delta_2^{A_2}$	none or low 5–95% 2–14%	Severe microcytic anaemia	Mediterranean lands, Asia south of latitude 40°N, Central Africa
High Hb-F (persistent foetal haemoglobin, F-gene, 'non-microcythaemic thalassaemia')	$\alpha_2^A\gamma_2^F$	100% in homozygotes 30% in heterozygotes	Symptomless; total Hb concentration normal even in homozygotes	Central Africa (?)
Heterozygotes for β-chain thalassaemia (Cooley's trait, thalassaemia minor)	$\alpha_2^A\beta_2^A$ $\alpha_2^A\delta_2^{A_2}$ $\alpha_2^A\gamma_2^F$	reduced raised in 96% raised in 50%	Microcytic anaemia, varying from very mild to severe	Mediterranean lands, etc.
Heterozygotes for β-chain thalassaemia and Hb-S, Hb-C or Hb-E (sickle-cell thalassaemia, etc.)	$\alpha_2^A\beta_2^{6\,Val}$ or $\alpha_2^A\beta_2^{6\,Lys}$ or $\alpha_2^A\beta_2^{26\,Lys}$		Combine the features of both heterozygous diseases; often more severe than either alone	As for Hb-S, Hb-C or Hb-E
α-Chain thalassaemias, Hb-H, Hb-Bart's (Cooley's anaemia, etc.)	$\alpha_2^A\beta_2^A$ β_4^A = Hb-H γ_4^F = Hb-Bart's $\delta_4^{A_2}$	in reduced amount	As in β-thalassaemia; probably only heterozygotes survive	Thailand, China, Greece

Inborn errors of amino-acid metabolism

In alkaptonuria the absence of homogentisate oxygenase prevents the catabolism of homogentisic acid to maleylacetoacetic acid with the result that homogentisic acid accumulates and is excreted in the urine. The renal clearance of homogentisic acid is very high.

Phenylketonuria, histidinaemia and maple syrup urine disease (leucinosis) resemble alkaptonuria in that each is caused by the genetically determined absence of an enzyme and the consequent accumulation of the relevant substrate. In each case, however, the substrate undergoes 'abnormal' reactions because of its high concentration, for example in phenylketonuria the transamination of phenylalanine to phenylpyruvic acid or β-imidazolylpyruvic acid and reduction to the α-hydroxy acids. Substrates of the missing enzymes in abnormally high concentrations, as well as the abnormal metabolites, are often toxic; they may cause brain damage in phenylketonuria and maple syrup urine disease, ochronosis and arthritis in alkaptonuria.

In albinism, though tyrosine is not converted to 3,4-dihydroxyphenylalanine (DOPA) and the latter is not converted to melanin, it is adequately metabolized by other pathways. The nature of the enzymatic defects in cystinosis, homocystinuria, hyperglycinaemia and oxalosis is still obscure.

Diseases arising from inborn errors of amino-acid metabolism are listed in Table 2. All involve some loss of survival fitness and many are virtually lethal. All are inherited as mendelian recessive characters, as would be expected in view of the fact that a mutant gene would tend not to survive if it produced a dominant character causing serious disability. Even recessively inherited lethal genes tend to vanish unless there is some compensating advantage to the heterozygote in some environments.

Table 2 Inborn errors of intermediary metabolism of amino acids

Condition	Defective enzyme	Biochemical features	Clinical features	Treatment	Reference
Alkaptonuria*	Homogentisate oxygenase	Urinary excretion of homogentisic acid	Urine darkens; ochronosis; arthritis in later life	None known	1, 2
Phenylketonuria**	Phenylalanine 4-hydroxylase	Phenylalanine accumulates in blood, CSF, etc.; urinary excretion of phenylpyruvic acid and related compounds	Severe mental deficiency, epilepsy, abnormal EEG, eczema, behavioural disorders	Diet low in phenylalanine beginning at early age	2, 3
Albinism***	*o*-Diphenol oxidase (tyrosinase)	Lack of melanin in skin, hair and eyes	Photophobia, nystagmus, carcinomata of the skin	None known	2, 4

* Incidence 1 in 100 000. ** Incidence varies from 1 in 3200 to 1 in 10^7 according to locality. *** Incidence 1 in 13 000.

le 2 (continued) Inborn errors of intermediary metabolism of amino acids

Condition	Defective enzyme	Biochemical features	Clinical features	Treatment	Reference
oitrous cretinism (several types)	(1) Tyrosine iodinase (2) Coupling enzyme (3) Deiodinase	Lack of thyroid hormone	Cretinism, goitre	Thyroid, thyroxine or tri-iodothyronine	5
laple syrup urine disease (leucinosis)	Enzyme responsible for oxidative decarboxylation of α ketoisocaproic, α-keto-β-methyl-n-valeric and α-keto-isovaleric acids	Leucine, isoleucine and valine accumulate in blood, CSF, etc, urinary excretion of the 3 keto acids and related compounds	Cerebral degeneration; usually early death. Milder form with partial enzyme deficiency, symptomless except during infections, etc	Diet low in leucine, isoleucine and valine	6
Cystinosis	Cystine reductase (?)	Cystine is deposited in reticulo-endothelial system, amino-aciduria, glucosuria, proteinuria, phosphaturia, dilute urine	Dwarfism, photophobia, renal acidosis, hypokalaemia, vitamin-resistant rickets; death before puberty A benign (non-renal?) variant occurs in adults	Palliative potassium salts, alkalis, vitamin D Diet low in cystine and methionine (efficacy doubtful)	7
Homocystinuria	L-Serine dehydratase	Urinary excretion of homocystine	Mental retardation, retinal defects, dislocated lenses, malar flush, thromboses	Diet low in methionine, high in cystine Pyridoxine	8
Hyperglycinaemia (several types)	(Uncertain, depends on type)	Glycine accumulates in blood, etc, urinary excretion of glycine and, in one type, methylmalonic acid	Neonatal lethargy and ketosis, neutropenia, hypo-γ-globulinaemia, mental retardation	Diet low in protein	9
Oxalosis	Excessive conversion of glycine to oxalic acid	Calcium oxalate accumulates in kidneys, heart, bone marrow and cartilages	Nephrocalcinosis leading to progressive renal failure	None known	10
Histidinaemia	Histidine ammonia-lyase	Urinary excretion of β-imidazolylpyruvic acid and related compounds	Speech defects, mental retardation in some	Diet low in histidine	11
Familial tyrosinaemia	(Uncertain)	Tyrosine level in blood and urine raised, urinary excretion of phenolic acids related to tyrosine, generalized amino-aciduria, glucosuria, fructosuria	Rapidly enlarging liver, jaundice, hypoprothrombinaemia, death common in infancy, survivors may have vitamin D-resistant rickets and acidosis	Diet low in tyrosine and phenylalanine (efficacy doubtful)	12
Hyperprolinaemia Type I	Pyrroline-5-carboxylate reductase	Hyperprolinaemia, urinary excretion of proline, glycine and hydroxyproline	Mental retardation, convulsions, renal disease, deafness	None known	13
Type II	Pyrroline-5-carboxylate dehydrogenase				
Hydroxyprolinaemia	3 Hydroxypyrroline-5-carboxylate reductase (?)	High levels of hydroxyproline in blood and urine	Mental retardation (?)	None known	13
Citrullinaemia	Argininosuccinate synthetase	High blood and urinary levels of citrulline, blood ammonia increased, urea excretion normal	Mental retardation, epilepsy, vomiting, ammonia intoxication	Diet low in protein	14 15
Argininosuccinic aciduria	Argininosuccinate lyase	[illegible] normal	[illegible]	Diet low in protein	15, 16

Table 2 (concluded) Inborn errors of intermediary metabolism of amino acids

Condition	Defective enzyme	Biochemical features	Clinical features	Treatment
Hyperammonaemia				
Type I	Ornithine carbamoyl-transferase	Blood ammonia about 10 mg/l; urea excretion normal	Mental retardation, ammonia intoxication	Diet low in protein (?)
Type II	Carbamoyl-phosphate synthase			

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Inborn errors of carbohydrate metabolism

Genetically determined absence of the appropriate intestinal enzyme causes inability to split lactose, sucrose or limit dextrin. Consumption of these substances may lead to diarrhoea and sometimes injury of the intestinal mucosa.

In galactosaemia, galactose is not converted to glycogen because of the absence of galactose-1-phosphate uridylyltransferase. Galactose 1-phosphate therefore accumulates and has a toxic effect due to its inhibition of phosphoglucomutase and other enzymes. Similarly, in fructose intolerance the absence of fructose-1-phosphate aldolase results in accumulation of fructose-1-phosphate, which causes severe hypoglycaemia, probably by inhibition of glucose-6-phosphatase. Defects in the metabolism of carbohydrates other than glycogen are listed in Table 3. With the exception of hereditary leucine-sensitive hypoglycaemia, all are probably or certainly inherited as mendelian recessive characters.

There are at least seven diseases due to an abnormality of glyco metabolism (Table 4). There may be failure to form this substan or a glycogen of abnormal structure may be laid down, or the g cogen deposited in various tissues may not be broken down n mally. In six of the seven diseases a specific enzymatic defect has b demonstrated, but not all of these resemble typical inborn errors metabolism in which a mutant gene fails to produce a normal zyme. In idiopathic generalized glycogenosis there is a deficien of α-glucosidase. In some, more severe, cases of Gierke's disea glucose-6-phosphatase is absent from the liver, but more often i present in diminished amount. A second enzyme, glucose-6-pho phate dehydrogenase, is also absent in some but not all persons wi Gierke's disease. Glucose-6-phosphatase deficiency and dextri 1,6-glucosidase deficiency occur in the same families; in these fa ilies at least, the mutant gene is unlikely to be directly responsit for the enzymatic defects. The status of amylopectinosis and of h patic glycogen phosphorylase deficiency is also somewhat uncerta

Table 3 Inborn errors of metabolism of carbohydrates other than glycogen

Condition	Defective enzyme	Biochemical features	Clinical features	Treatment	Reference
Galactose diabetes	Galactokinase	Urinary excretion of galactose	Cataracts	Diet low in galactose from early infancy	1
Galactosaemia*	Galactose-1-phosphate uridylyl-transferase	Galactose and galactose 1-phosphate accumulate in tissues and body fluids	Liver damage, cataracts, mental deficiency, renal tubular dysfunction; often early death	Diet free from galactose	2
Fructose intolerance	Fructose-1-phosphate aldolase	Fructose and fructose 1-phosphate accumulate	Severe hypoglycaemia after ingesting fructose, sucrose, etc.	Avoidance of fructose and fructose precursors such as sucrose	3, 4
Fructosuria	Fructokinase	Urinary excretion of ingested fructose	Benign	Unnecessary	3

* Incidence 1 in 70 000.

Table 3 (continued) Inborn errors of metabolism of carbohydrates other than glycogen

Condition	Defective enzyme	Biochemical features	Clinical features	Treatment	Reference
Pentosuria*	L-Xylulose reductase	Urinary excretion of L-xylulose	Benign	Unnecessary	4
Alactasia	β-Galactosidase (lactase) in intestinal mucosa (lifelong)	Lactose not hydrolysed in small intestine	Diarrhoea; failure to gain weight	Avoidance of lactose	6 7
Lactose intolerance	Probably intestinal β galactosidase (temporarily)	Lactose not utilized, lactosuria, amino-aciduria	Diarrhoea, possible death in infancy	Avoidance of lactose and sucrose	6 7
Sucrose intolerance	[illegible]	[illegible]	Diarrhoea after ingesting sucrose, less severe diarrhoea after ingesting starch	Avoidance of sucrose, diet low in starch	7
Hereditary leucine-sensitive hypo-glycaemia**	–	Hypoglycaemia accentuated by giving leucine or protein, through release of insulin	Hypoglycaemic convulsions, varying degrees of mental retardation, sometimes symptomless	Carbohydrates with every protein meal	8

* Incidence 1 in 50 000

** Inherited as a dominant character causing 40–60% of cases of idiopathic infantile hypoglycaemia

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Table 4 Inborn errors of glycogen deposition or utilization[1]

Condition	Cori type	Biochemical features	Clinical features
Glucose-6-phosphatase deficiency (GIERKE's disease)	1	Normal glycogen accumulates in liver and kidney	Hepatomegaly, hypoglycaemia, stunted growth with retarded bone age, etc
Idiopathic generalized glycogenosis (POMPE's disease)	2	Normal glycogen accumulates in all organs	Cardiac failure, muscle hypotonia, neurological disorders, death in infancy
Dextrin 1,6-glucosidase (debrancher) deficiency (limit dextrinosis, FORBES' disease)	3	Abnormal glycogen with short branches deposited in liver and, sometimes, skeletal and cardiac muscle	Hepatomegaly, hypoglycaemia, less severe than GIERKE's disease
α Glucan branching glycosyl transferase (brancher) deficiency (amylopectinosis, ANDERSEN's disease)	4	Abnormal carbohydrate with long inner and outer branches deposited in liver, spleen and lymph nodes	Hepatic cirrhosis, death within two years of birth
Glycogen phosphorylase (glycogen phosphorylase of the muscle) deficiency (MCARDLE's syndrome)	5	Moderate accumulation of normal glycogen in skeletal muscles, lactate and pyruvate levels in blood fall during exercise	Generalized muscular fatiguability and pain
Glycogen phosphorylase (hepatic glycogen phosphorylase) deficiency (HERS' disease)	6	Normal glycogen accumulates in liver, phosphorylase content of liver and leucocytes reduced	Hepatomegaly, relatively benign
Deficiency of UDPglucose-glycogen glucosyltransferase (glycogen synthetase)	–	Liver glycogen almost completely absent	Severe fasting hypoglycaemia

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Inborn defects of renal transport mechanisms[1]

Many of the substances in the glomerular filtrate are normally reabsorbed with high efficiency in the proximal renal tubule. This active process requires specific receptor sites on the cells lining this region. One type of site absorbs cystine, lysine, arginine and ornithine. In cystinuria[2] these sites are absent or largely inactive, so that cystine, lysine, arginine and ornithine are very inefficiently reabsorbed from the glomerular filtrate and appear in the urine. Cystinuria is determined by a single pair of genes. Abnormal homozygotes excrete all four amino acids and tend to form cystine stones. Some heterozygotes excrete moderately increased amounts of cystine and lysine, others are completely normal.

In the Hartnup syndrome[3] the renal tubular reabsorption of a different, and larger, group of amino acids is defective. Moreover, since absorption of tryptophan from the gut is also defective, bacterial metabolites of tryptophan are excreted in abnormal amounts.

There are several conditions characterized by one or more of the following: renal glucosuria[4], phosphaturia[5], renal acidosis[6], generalized amino-aciduria[7]. Each is caused by loss of some specific function of the proximal renal tubule, often inherited in dominant fashion. With the exception of renal glucosuria, the tubular defect is associated with disease in some individuals. Phosphogluco-amino-aciduria[8] (Debré-de Toni-Fanconi syndrome), 'benign amino-aciduria'[9] and osteomalacia with amino-aciduria[10] (adult Fanconi syndrome) were formerly considered to be separate entities, but the demonstration of renal loss of phosphate and bicarbonate in two cases of 'benign amino-aciduria'[9] closed the gaps between it and the other two conditions. It seems probable that all three are manifestations of the same primary renal tubular defect[11], the clinical effects varying markedly from individual to individual, both in age at onset and severity. Cystinosis must be distinguished from these conditions since the progressive loss of renal tubular function in cystinosis is secondary to some more fundamental metabolic defect, as in galactosaemia and Wilson's disease; these three diseases are recessively inherited.

Glycine is reabsorbed from the glomerular filtrate by a nism probably specific for glycine. In glycinuria[12] this mec is defective; the condition is dominantly inherited.

In nephrogenic diabetes insipidus[13] the distal tubule a lecting duct do not respond to vasopressin by becoming able to water.

In renal glucosuria and glucose-galactose malabsorption[14] a disturbance of the reabsorption of glucose from the renal t

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Table 5 Some inborn defects of transport mechanisms

Condition	Site of defect	Biochemical signs	Clinical features	Treatment	Genetics
Cystinuria	Renal tubules and gut wall	Excessive urinary excretion of cystine, lysine, arginine and ornithine	Calculi of cystine in urinary tract. Often symptomless	High water intake, alkalinization; penicillamine	Two forms, bot recessive
Hartnup disease	Renal tubules and gut wall	Delayed intestinal absorption of tryptophan, etc.; excessive urinary excretion of indoles and many amino acids	Cerebellar ataxia, photosensitive dermatitis	Nicotinamide	Recessive
Glucose-galactose malabsorption	Wall of intestine, renal tubules	Glucose, galactose and products of microbial fermentation in faeces; glucosuria	Diarrhoea; dehydration, sometimes fatal	Diet with fructose as sole carbohydrate	Autosomal reces sive (?)
Glycinuria	Renal tubules	Glycine excretion increased	Probably benign	None known	Dominant
Renal glucosuria	Renal tubules	Glucosuria; reduced *Tm* (glucose) in type A; increased splay of glucose reabsorption curve in type B	Benign	None known	Dominant
Hypophosphataemia (phosphaturia)	Renal tubules	Urinary loss of phosphate	Rickets resistant to vitamin D; sometimes symptomless	Phosphate infusions; large doses of vitamin D or dihydrotachysterol	Sex-linked with expression in mo hemizygotes, son heterozygotes

ble 5 (continued) Some inborn defects of transport mechanisms

Condition	Site of defect	Biochemical signs	Clinical features	Treatment	Genetics
nal acidosis	Renal tubules	Impaired hydrogen-ion exchange in glomerular filtrate; hypercalcinuria	Hyperchloraemia, acidosis, nephrocalcinosis, nephrolithiasis, rickets or osteomalacia. Sometimes symptomless	Alkalis	Sometimes dominant
hosphoglucoamino-aciduria (DEBRÉ-DE TONI-FANCONI syndrome) enign familial amino-aciduria' steomalacia with amino-aciduria (adult FANCONI syndrome)	Renal tubules	Urinary loss of glucose, phosphate, amino acids, protein and bicarbonate	Sometimes benign, phosphate loss, if severe, causes vitamin D-resistant rickets and dwarfism in children, osteomalacia in adults, acidosis in many cases	Alkalis, vitamin D or dihydrotachysterol, phosphate infusions	Dominant
ephrogenic diabetes insipidus	Distal renal tubules and collecting ducts	Urine dilute and copious	Dehydration, mental retardation	Water, diet low in salt and nitrogen, chlorothiazide	Sex-linked recessive

born errors of purine and pyrimidine metabolism

[illegible]

lated compounds

In the very rare condition of xanthinuria, xanthine and not uric acid is excreted as the end-product of purine metabolism owin[g to] lack of the enzyme xanthine oxidase

Orotic-aciduria is due to a failure to synthesize uridylic acid fr[om] orotic acid (see page 438). A consequence is megaloblastic anae[mia] and retarded growth

β-Aminoisobutyric acid is a breakdown product of thymine ([see] page 401) [illegible]

able 6 Inborn errors of purine and pyrimidine metabolism

Condition	Defective enzyme or system	Biochemical features	Clinical features	Incidence and genetics	Refe[r]enc[e]
Gout (hyperuricaemia)	Excessive synthesis of uric acid from precursors	Concentration of uric acid increased in serum and often in urine	[illegible] cases	[illegible]	[illegible]
Xanthinuria	Deficiency of xanthine oxidase and defective renal tubular reabsorption of xanthine	Xanthine excreted in large amounts	Xanthine calculi in urinary tract	Rare	2
Orotic-aciduria	Absence of orotidine-5'-phosphate pyrophosphorylase and/or decarboxylase	Orotic acid accumulates and is excreted in urine	Severe megaloblastic anaemia, orotic-acid crystalluria	Very rare, recessive	3
β-Aminoisobutyric-aciduria	Deficiency of a catabolic enzyme	High urinary excretion of β aminoisobutyric acid	Harmless	0–46% depending on ethnic group, recessive	4

Hyperbilirubinaemia[1] and porphyria[2]

Several inborn errors of the metabolism of pyrrole derivatives are known. The main stages of the synthesis of haem from glycine and succinyl-coenzyme A are as follows (for fuller details see page 355):

glycine + succinyl-coenzyme A
↓
α-amino-β-ketoadipic acid
↓
δ-aminolaevulinic acid
↓
porphobilinogen
↓ ↓

uropor-phyrin III ⇌ uropor-phyrinogen III ↓ coproporphyrin III ← coproporphyrinogen III ↓ protoporphyrin IX ← protoporphyrinogen IX
protoporphyrin IX → (+ Fe) → haem

uroporphyrinogen I ⇌ uroporphyrin I
↓
coproporphyrinogen I → coproporphyrin I

Complete failure of any of the enzymes leading to the formation of haem is incompatible with life since haem is an essential part not only of haemoglobin and myoglobin but also of a number of enzymes, especially the cytochromes. Deficiencies of the enzymes synthesizing haem can be due to inborn errors or the action of toxic substances. Thus among other effects, lead poisoning ishes the activity of the enzymes metabolizing δ-aminolac acid, so that the latter is excreted in the urine.

In the commonest forms (intermittent acute porphyr porphyria cutanea tarda hereditaria) the *primary biochemical* is in the liver. These have been called respectively the Swedi South African forms of hepatic porphyria, though both occu countries. Mixed porphyria and porphyria variegata are terms applied, in particular, to the form of porphyria cutanea hereditaria common in South Africa.

Hepatic porphyria (or cutaneous hepatic porphyria) is cau oxidation of porphyrinogens to porphyrins in the liver. Th phyrins so produced cannot be used for haem synthesis a excreted via the bile. The condition can be acquired by alcoh by ingestion of hexachlorobenzene, or as a result of liver d

Haem is normally broken down to bilirubin, which is conju with glucuronic acid in the liver and excreted as the conjug the bile. Free bilirubin in high concentration, in contrast conjugate, is toxic. Of the four known inherited conditions le to hyperbilirubinaemia only one, the CRIGLER-NAJJAR synd can be definitely attributed to the absence of an enzyme. The three conditions may be the results of defects of a transport sy

References

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Table 7 Inborn defects of metabolism of pyrrole derivatives (hyperbilirubinaemia and porphyria)

Condition	Defective enzyme or system	Biochemical effects	Clinical features	Treatment	Incidence a genetics
Congenital non-haemolytic jaundice (CRIGLER-NAJJAR syndrome)	Bilirubin-glucuronic acid conjugating system	Serum bilirubin 150–400 mg/l (all free)	Severe kernicterus; often early death; sometimes symptomless	None known	Recessive
Constitutional hepatic dysfunction (GILBERT's disease)	Bilirubin-glucuronic acid conjugating system (?)	Serum bilirubin 10–30 mg/l (all free)	Probably harmless	None necessary	Probably dominant
Chronic idiopathic jaundice (DUBIN-JOHNSON syndrome)	Probably faulty hepatic excretion of pigment, etc. into the bile	Slight hyperbilirubinaemia (bilirubin all conjugated); unidentified brown pigment in liver parenchyma cells	Benign; sometimes liver enlargement and tenderness	None	Probably dominant
ROTOR syndrome	Possibly faulty hepatic excretion	Serum bilirubin 40–76 mg/l, half free and half conjugated; no pigment in liver	Some liver tests abnormal	None	Probably dominant
Congenital erythropoietic porphyria (GÜNTHER's disease)	Probably uroporphyrinogen isomerase	Uroporphyrin I and coproporphyrin I in tissues, plasma, urine and faeces	Often early death; photosensitization leading to severe scarring, erythrodontia; haemolytic anaemia	Splenectomy, protection from sunlight	50 known cases; recessive
Intermittent acute porphyria	Large amounts of δ-aminolaevulinic acid synthetase in liver	Porphobilinogen and δ-aminolaevulinic acid excreted in urine	Often intermittent; abdominal pain, neurosis and psychosis, peripheral neuritis, paralysis, generalized demyelination; mortality high	Avoidance of barbiturates	Incidence 0.015–0.1%; dominant

'e 7 (continued) Inborn defects of metabolism of pyrrole derivatives (hyperbilirubinaemia and porphyria)

Condition	Defective enzyme or system	Biochemical effects	Clinical features	Treatment	Incidence and genetics
rphyria cutanea tarda hereditaria	Excessive hepatic porphyrin production	Faecal porphyrins high in remission; urinary por- [illegible]	Symptomless [illegible] ... sometimes mental symptoms	[illegible] alcohol and barbiturates	[illegible]
iopathic copro-porphyria	Uncertain	Large amounts of copro-porphyrin III in urine and faeces, amino-aciduria	Harmless	None	Rare; recessive
rythropoietic protoporphyria	Uncertain	Large amounts of proto-porphyrin in erythro-cytes, normoblasts and (sometimes) faeces	Relatively mild photo-sensitive dermatitis, erythema, itching, mild oedema	Avoidance of bright sunlight	Rare; dominant

lpidoses[1]

A group of pathological conditions, generally grouped together 'lipidoses' are either [illegible]

[illegible] This is also true of the two forms of amaurotic familial idiocy. However, it is not certain that the different forms of NIEMANN-PICK disease are genetically distinct, they may differ only in site and rate of lipid deposition, and this may also be true of metachromatic leucodystrophy.

References

[1] V [illegible]

Table 8 Lipidoses

Condition	Lipid accumulating	Site	Clinical features	Age at which symptoms appear	Genetics	Reference
GAUCHER's disease (a) 'Adult' (b) Acute infantile (c) Juvenile and adult neurological	Glucocerebroside	Spleen, liver, bone marrow, leucocytes; Brain in (b) and (c), lung in (b)	Splenomegaly, often gross, hepatomegaly; anaemia, bone disorder, purpura, cerebral degeneration in (b) and (c)	(a) 1–60 years (b) 1st or 2nd half year of life (c) 6–20 years	(a), (b) and (c) in different families, all recessive	1
TAY SACHS' disease (infantile amaurotic familial idiocy)	Ganglioside G_{M2} (G_2), amino-glycolipid	White and grey matter of the brain	Cherry-red spot, progressive cerebral degeneration, death at age 1–5 years	Usually 4–6 months, sometimes earlier	Recessive	2
Juvenile and adult amaurotic familial idiocy	[illegible]	[illegible]	[illegible]	From 5 years onwards	Probably recessive	2

Table 8 (continued) Lipidoses

Condition	Lipid accumulating	Site	Clinical features	Age at which symptoms appear	Genetics
NIEMANN-PICK disease (a) Acute infantile (b) Cerebral juvenile (c) Noncerebral	Mainly sphingomyelin	Spleen, bone marrow, liver; usually also brain and retina	Often cherry-red spot; hepatosplenomegaly; hepatic cirrhosis; usually cerebral degeneration and death in first 2½ years. Some adult cases are without neurological involvement	(a) From birth (b) Childhood (c) Up to 30 years or later	(a) Recessive (b) Recessive (c) Uncertain
Metachromatic leucodystrophy (a) Infantile (b) Adult	Sulphatides	Brain, kidney, urine, gall-bladder	(a) Cerebral and cerebellar degeneration; spasticity; dementia; death after 1–6 years (b) Psychotic changes; blindness; aphasia; tetraplegia. Death after 3–12 years	(a) 1–2 years (b) Late childhood or adulthood	(a) Recessive (b) Uncertain
Essential familial hyperlipaemia	Triglycerides, lipoproteins	Blood plasma (chylomicrons)	Hepatosplenomegaly; sometimes xanthomata. Relatively benign	Usually early childhood	Complex
Hypercholesterolaemia	Cholesterol (free and esterified), phosphatides, sometimes triglycerides	Blood plasma (lipoproteins), tendons, skin, blood vessels	Cutaneous and tendinous xanthomata; atheroma of endocardium, coronary arteries or great vessels	From childhood onwards	Usually dominant

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Inborn errors of corticosteroid metabolism[1]

Certain forms of adrenal hyperplasia have their origin in an inborn defect in the biosynthesis of steroids. The commonest is a defect in the hydroxylation of the steroid skeleton at C-21 due to a deficiency of steroid 21-hydroxylase, the result being a diminished synthesis of 21-hydroxysteroids. Since these steroids have no effect on the pituitary, the latter produces increased amounts of ACTH, resulting in further stimulation of the synthesis of 21-deoxysteroids. Some of these 21-deoxysteroids are precursors of androgens, the augmentation of which is the reason for the progressive virilization seen in these patients. When the deficiency of steroid 21-hydroxylase is very marked, practically no 21-hydroxysteroids are formed. This results in limitation also of aldosterone synthesis and the accumulation of progestogens, which act as aldosterone antagonists. The excretion of sodium by the kidneys is therefore increased, and in infants with this defect there is extreme loss of salt in the urine and possibly crises like those seen in ADDISON's disease.

A rarer form of inborn adrenal hyperplasia is due to deficiency of steroid 11β-hydroxylase, resulting in increased formation of 11-deoxycorticosterone and excessive excretion of metabolites of this substance in the urine. Unlike patients with the defect of 21-hydroxylation, such persons excrete only small amounts ketosteroids in the urine and they show hardly any incr pregnanetriol. 11-Deoxycorticosterone causes sodium ret and this is probably the cause of the arterial hypertension these patients.

Deficiency of 3β-hydroxysteroid dehydrogenase is rar blocks the formation of progesterone from pregnenolone. A the defect in 21-hydroxylation, the result is loss of salt in the but clinically the condition differs from inborn adrenal hype in the manner in which it affects differentiation of the e genitalia in the foetus.

A case of deficiency of steroid 17α-hydroxylase has be ported[2]; here the adrenal cortex produced excessive amou corticosterone and deoxycorticosterone, with consequent hypertension.

The various forms of inborn adrenal hyperplasia are pr each inherited through an autosomal recessive gene.

References

[1] SOFFER et al., *The Human Adrenal Gland*, Lea & Febiger, Philadelphia STEMPFEL and TOMKINS, in STANBURY et al. (Eds.), *The Metabolic Inherited Disease*, 2nd ed., McGraw-Hill, New York, 1966, page 635
[2] BIGLIERI et al., *J. clin. Invest.*, 45, 1946 (1966).

(For references see pages 460–461)

min A[1 2]

nistry[3]

tamin A and the carotenes are soluble in fats, insoluble in water, readily oxidized In the absence of oxygen they are stable to , alkalis and heat. On the *cis-trans* isomerism of the carotenes vitamin A see ZECHMEISTER[4]. For structure and properties of min A and related compounds see the table on pages 458–459.

y

ological[5] Mainly by the standardized growth test on vitamin A-ient rats
hemical[6]. Spectrophotometrically in pure solution (vitamin A 8 nm, carotenes at ca. 450 nm) or colorimetrically, for instance antimony trichloride (CARR-PRICE reaction), in biological rial chromatographically after suitable extraction.

ts

'itamin A. 1 International Unit (IU) = 0.344 μg *all-trans* vita-A_1 acetate = 0.300 μg *all-trans* vitamin A_1. 1 US Pharmacopeia P) Unit = 1 International Unit.
arotenes 1 International Unit (IU) = 0 6 μg β-carotene, equiv-t in activity to 1 IU vitamin A

genesis[7 8]

he carotenes are synthesized by the higher plants, algae and tosynthetic bacteria and are found in concentrated form in the roplasts Acetate is converted by condensation and decarboxy-on into isopentenyl pyrophosphate, from which a C_{20} terpenol ophosphate arises by condensation This substance gives rise by her condensation to a carotenoid precursor with 40 C-atoms, bably phytoene The various carotenes arise by dehydrogena-, cyclization, isomerization, hydration and hydroxylation Caro-es with a β-ionone ring are broken down in the animal organism vitamin A, more probably by fission in the middle of the chain n by successive β-oxidation from the end of the isoprenoid in[9]. In the liver oils, vitamin A is present in the esterified form

ake and excretion

n the USA the daily diet contains ca 7500–10000 IU (2 3–3 mg) vitamin A[10 11] About a half of the apparent vitamin intake is in form of the provitamin

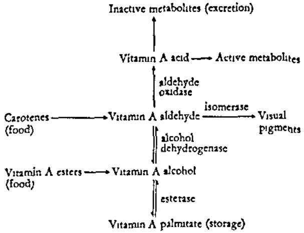
[illegible]

es are less easily absorbed than vitamin A and part of those in-

[illegible]

Vitamin A is stored in the liver, the carotenes mainly in the fatty ssues About 90% of the whole vitamin A of the body is stored in e liver, the liver reserves (up to 300 μg vitamin A per gramme liver more[14]) are sufficient to meet the body's requirements of the tamin for one year or more[2] These reserves, however, are rapidly ed up in infections, hyperthermia and poisoning[2] 90–95% of the tamin A in the liver is present as palmitate, the remainder as alde-de and alcohol[14 15] When any organ requires vitamin A, the ters in the liver are hydrolysed and the free alcohol transported by e blood to where it is required In the tissues, particularly in the ver, vitamin A alcohol and aldehyde are rapidly oxidized to vita-in A acid, this substance is not stored, however, but rapidly bro-en down[8 17] An active metabolite of vitamin A acid has recently een identified but its composition is unknown[18]. After adminis-tration of tagged vitamin A to rats, radioactivity can be detected in the bile, urine and faeces[8], the presence of vitamin A and/or its metabolites in bile points to enterohepatic circulation of the vita-min[19]

Metabolism of vitamin A



Function

Vitamin A is of great importance for maintenance of health and life, normal growth, the visual process and reproductivity It ap-pears to be necessary for the stability of the lipoprotein membrane

[illegible]

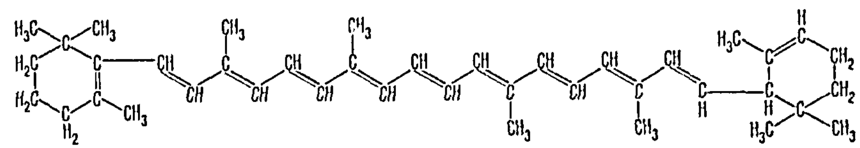
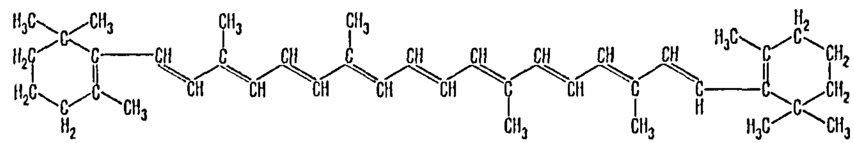
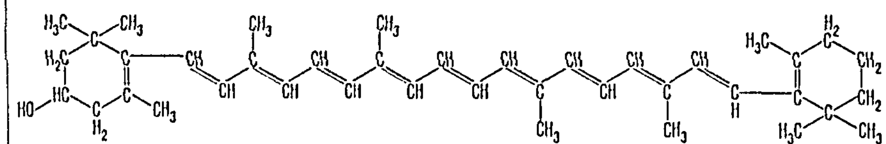
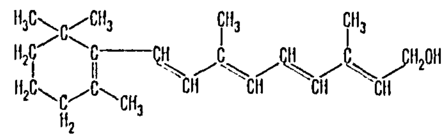
min A acid, while very active in maintaining growth, is not capable of maintaining reproductivity.

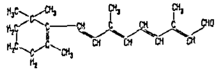
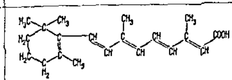
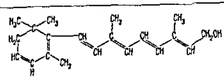
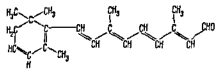
Metabolic functions of vitamin A[20]

Active form	Biochemical reaction	Clinical effect
Vitamin A alcohol or other active form	Unknown	Reproduction in both sexes
Vitamin A aldehyde	Reaction with opsin	Visual process
Vitamin A acid or other active form	Liberation of proteolytic enzymes	Breakdown of cartilage
	Synthesis of muco-polysaccharides	Stimulation of mucous secretion in the epithelium
	Synthesis of corti-costerone	Lesions in the adrenal cortex, interference with gluconeogenesis in deficiency states

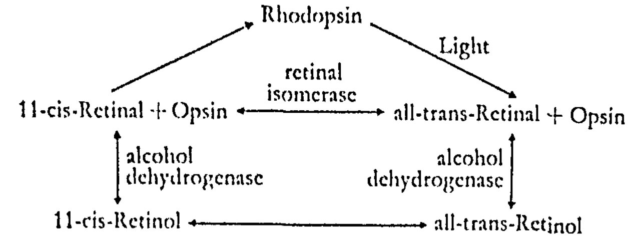
The vitamin A aldehydes retinal and dehydroretinal form together

Structure and properties of vitamin A_1 and related compounds

Names*	Formula and mol. wt.	Structure	Physical properties	Occurrence	Relative activity
α-Carotene	$C_{40}H_{56}$ 536.89		Violet to red crystals M.p. 187 °C (benzene/methanol)	Palm oil, mountain ash berries	50
β-Carotene	$C_{40}H_{56}$ 536.89		Violet to red crystals M.p. 180 °C	Plants, fruits	100
Cryptoxanthene (3-hydroxy-β-carotene)	$C_{40}H_{56}O$ 552.89		Red platelets M.p. 158 °C	Maize	50
Vitamin A_1 (*all-trans*) (retinol*, axerophthol)	$C_{20}H_{30}O$ 286.46		Yellow prisms M.p. 62–64 °C	Liver of marine fish	100
9-*cis*-Vitamin A_1 (*iso-a*)	$C_{20}H_{30}O$ 286.46	As *all-trans* vitamin A_1 but with double bond at C-9 in *cis* configuration	Yellow prisms M.p. 82 °C	–	21
11-*cis*-Vitamin A_1 (*neo-b*) (11-*cis*-retinol)	$C_{20}H_{30}O$ 286.46	As *all-trans* vitamin A_1 but with double bond at C-11 in *cis* configuration	Orange-yellow oil	Retina	23

13-*cis*-Vitamin A_1 (*neo-a*)	$C_{20}H_{30}O$ 286.46	As *all trans* vitamin A_1 but with double bond at C-13 in *cis* configuration	Yellow prisms M.p. 58 °C	Fish liver	75
Vitamin A_1 aldehyde (*all trans*) (retinal*, retin-aldehyde*, β-retinene, retinene$_1$)	$C_{20}H_{28}O$ 284.45		Orange prisms M.p. 58 °C	Citrus fruits, green vegetables, liver	91
11-*cis*-Vitamin-A_1 aldehyde (*neo-b*) (11-*cis* retinal)	$C_{20}H_{28}O$ 284.45	As *all-trans* vitamin-A_1 aldehyde but with double bond at C-11 in *cis* configuration	Orange prisms M.p. 64 °C	Eyes of crustacea	48
Vitamin-A_1 carboxylic acid (*all-trans*) (retinic acid*)	$C_{20}H_{28}O_2$ 300.44		Yellow needles M.p. 179 °C	Tissues?	~65
Vitamin A_2 (3-dehydroretinol*)	$C_{20}H_{28}O$ 284.45		Yellow needles M.p. 63–65 °C	Liver of freshwater fish	40
Vitamin A_2 aldehyde (3-dehydroretinal*, 3-dehydroretinaldehyde*, α-retinene, retinene$_2$)	$C_{20}H_{26}O$ 282.43		Orange-red prisms M.p. 78 °C	Retina in fish	

* Trivial names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry [*Biochim. biophys. Acta (Amst.)*, 107, 1 (1965)]



Vitamin A and carotene in their protein-bound form are thought to participate in an analogous manner in the sense of smell[24].

Requirements and deficiency symptoms

The requirement of vitamin A is proportional to the body weight. Daily requirements in health allowing for some reserve are 2500 IU vitamin A, 4000 IU carotene in fats, 7500 IU in green vegetables or 12000 IU in boiled carrots[26]. In 10- to 15-year-old boys 1700 IU vitamin A are sufficient to maintain a plasma level of 300 $\mu g/l$[27]. For infants from birth to 5 months it is assumed that exclusive breast-feeding can provide sufficient vitamin A[25]. For recommendations of official bodies see the tables on pages 493–494.

Good sources of vitamin A are the fish oils (cod 1000, herring 5000, halibut and tunny 50000–100000 IU/g), liver, milk fat and egg yolk; green vegetables and carrots are rich in carotenes. See also pages 499–515.

Causes of vitamin A deficiency[2] are inadequate dietary intake, impaired absorption (fat deficiency) or storage, disturbances in the conversion of carotene into vitamin A, or rapid depletion of the body's reserves. Impairment of absorption or storage is seen in coeliac disease, cystic fibrosis of the pancreas, ulcerative colitis, pancreatectomy, obstruction of the biliary ducts and cirrhosis of the liver. Conversion of carotenes may also be impaired in diabetes and hyperthyroidism. Some infections result in disappearance of vitamin A from the blood. The typical lesions of vitamin A deficie[n]... are night blindness, xerosis or keratinization of various memb... (particularly xerophthalmia) and the formation of defective ... tissue and dentine during growth. The most sensitive test for ... min A deficiency is measurement of dark adaptation of the e... determination of vitamin A concentration in the serum is less ... ble since the serum level does not fall until the body's reserve... fully depleted[2]. In many countries of South America, Asia ... Africa xerophthalmia is still one of the commonest causes of b... ness in children[29, 30]. Other manifestations of vitamin A defici... are Bitôt's spots on the conjunctiva and roughness of the skin... to hyperkeratosis of the hair follicles. In animals vitamin A defi... cy has serious effects in pregnancy and is a cause of infertility ... congenital deformities[31].

Vitamin A deficiency symptoms in pregnancy and at various ages (modified from McLaren and Halasa[30])

	Cause of deficiency	Symptoms
Pregnancy	Dietary carotene deficiency, increased requirement, depletion following repeated pregnancies	Low plasma level of vitamin A, low liver reserves, xerophthalmia (rare), Bitôt's spots (occasionally)
Foetus		Low liver reserves, xerophthalmia (rare), abortion (?), congenital deformities (?)
Up to 12 months	Inadequacy of breast milk, low vitamin A content of breast milk, bottle feeding, infections	Low plasma level of vitamin A, depletion of liver reserves, xerophthalmia (fairly common), Bitôt's spots (rare)
Up to 5 years	Breast feeding continued too long, dietary deficiency, infections	Commonest cause of conjunctival xerosis, xerophthalmia, Bitôt's spots (occasionally)
School age	Dietary deficiency of carotene, vitamin A, fats and proteins	Conjunctival xerosis and Bitôt's spots (main symptoms), night blindness, follicular hyperkeratosis (occasionally)
Adults	Dietary deficiency, infections, cirrhosis of the liver, pancreatic disease	Night blindness (main symptom), Bitôt's spots (occasionally), xerophthalmia (rare), follicular hyperkeratosis (occasionally)

Treatment and toxicity

Deficiency symptoms should be treated by giving vitamin ... doses of up to 25000 IU (corresponding to ca. 30 ml liver ... Xerophthalmia calls for initially higher doses (5000 IU/kg b... weight daily for 5 days)[29, 30]. When liver oils are given in l... doses, vitamin D may be ingested in toxic amounts, even thoug... has been shown that vitamin A in large doses diminishes the t... effect of vitamin D[32].

Protracted treatment with high doses of vitamin A (for insta... 100000 IU or more per day in children) may result in toxic sy... toms such as anorexia, alopecia, affections of the skin and muc... swelling of the bones and diaphyses of the limbs, anaemia, enla... ment of the liver and spleen and headache. All these symptoms ... reversible and disappear rapidly on cessation of the treatment[2]. ... children overdosage of vitamin A may interfere with bone devel... ment and lead to premature fusion of the epiphyses[33].

In some countries vitamin A is given prophylactically to ne... born children and infants in daily doses of 7500–10000 IU. Beca... of the danger of possible intoxication, however, it is better to rest... prophylactic doses to 2500 IU per day[34].

Acute vitamin A intoxication has been observed following t... consumption of polar bear liver, which contains 20000 IU p... gramme[35, 36]; whale liver contains 4400 IU vitamin A per gramm... swine's liver only 100–150 IU per gramme[36].

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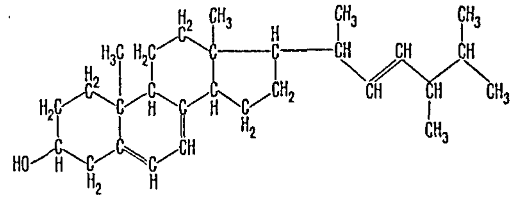
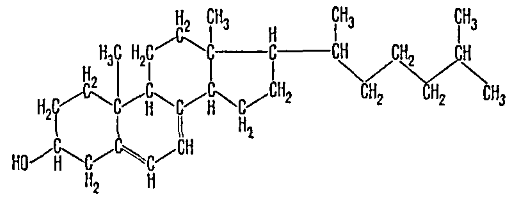
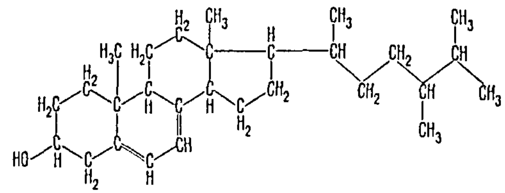
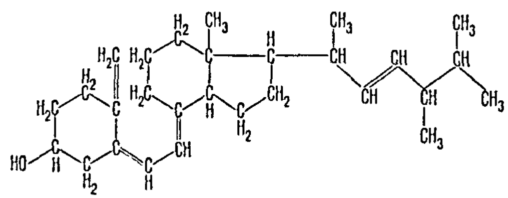
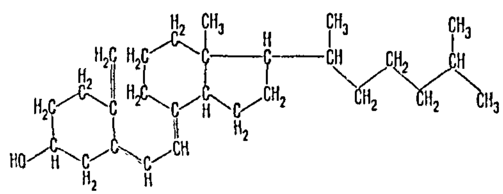
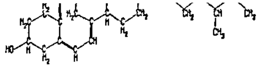
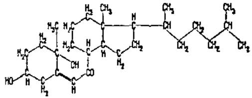
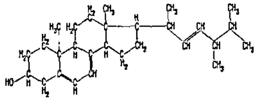
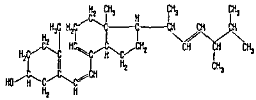
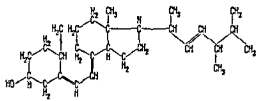
Structure and properties of vitamin D and related compounds

Names*	Formula and mol. wt.	Structure	Physical properties	Occurrence	Antirachitic activity
Ergosterol	$C_{28}H_{44}O$ 396.66		M.p. 168 °C (with 1½ H_2O)	Yeast, ergot, hens' eggs	None (provitamin D_2)
7-Dehydrocholesterol	$C_{27}H_{44}O$ 384.65		M.p. 150 °C (anhydrous)	Higher animals, man	None (provitamin D_3)
22-Dihydroergosterol	$C_{28}H_{46}O$ 398.68		M.p. 152 °C	Synthetic	None (provitamin D_4)
Vitamin D_2 (ergocalciferol*)	$C_{28}H_{44}O$ 396.66		M.p. 115–118 °C	Formed by irradiation of ergosterol	In rats similar to, in chicks and apes less than that of vitamin D_3
Vitamin D_3 (cholecalciferol*)	$C_{27}H_{44}O$ 384.65		M.p. 84–85 °C	Formed by irradiation of 7-dehydrocholesterol. In fish-liver oils, egg yolk, milk	Antirachitic

					
Ketone 250	$C_{27}H_{46}O_3$ 418 67		M.p 73 °C	Plants, fish-liver oils	One-tenth that of vitamin D_3
Lumisterol	$C_{28}H_{44}O$ 396 66		M p 118 °C	Formed by irradiation of ergosterol	None
Tachysterol	$C_{28}H_{44}O$ 396 66		Oil, readily oxidizing in air	Formed by irradiation of ergosterol	None (hypercalcaemic effect)
Dihydrotachysterol	$C_{28}H_{46}O$ 398.68		M.p. 125–127 °C	Synthetic	400 times less active than vitamin D_2 (same hyper-calcaemic effect)

* Trivial names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry [*Biochim biophys Acta (Amst)*, 107, 1 (1965)].

(b) FANCONI's syndrome
(c) primary vitamin D resistance
(d) renal insufficiency

The clinical symptoms of rickets are pain in the limbs, particularly the legs, genu valgum, bending of the long bones, thickening of the synchondroses of the ribs and of the joint epiphyses, and protuberance of the forehead. *Tetany is also an occasional symptom.* The radiological changes consist in widening of the epiphyses combined with disorganization of the epiphyseal disk, and appearance of a cup-shaped structure in place of the normal, distinct, straight boundary between metaphysis and epiphysis. The biochemical changes observed are slight lowering of the plasma calcium level, marked lowering of the plasma phosphate level, reduced urinary calcium excretion, increased phosphate clearance, increased phosphate excretion index and a rise in the plasma concentration of alkaline phosphatase; *the calcium phosphate product in the plasma* is lower than normal. One of the first signs of vitamin D deficiency is an increase in the amino-acid content of the urine[23].

Primary vitamin D-resistant rickets is congenital and usually hereditary. It is characterized by lower plasma phosphate levels and an increase in the phosphate excretion index. The vitamin D activity of the serum must be 10–20 times the normal value if the calcium metabolism is to be restored to normal[24]. This form of rickets may be due to a defect of vitamin D metabolism[25, 35] and excretion.

Treatment

Prophylaxis of rickets: Sun-baths or quartz lamp treatment, 400 IU vitamin D per day in the pure form or as cod-liver oil.

Treatment of rickets: Rickets and osteomalacia due to a simple deficiency of vitamin D respond to daily oral doses of 3000 IU vitamin D[19]; in premature infants and children with impaired absorption these should be given intramuscularly. Treatment with massive doses has the disadvantage that there is uncertainty as to the extent to which single high doses are absorbed. High vitamin D doses are called for in primary vitamin D-resistant rickets, and treatment should begin with 50 000 IU per day[26]. Complete disappearance of the radiological and biochemical symptoms has been reported with a total of 5–400 million IU, depending on the individual[24]. The maintenance dose, again depending on the individual, ranges from 1000 to 500 000 IU per day[24]. If growth of the long bones is to proceed normally, treatment must be started immediately after birth[27].

Treatment of lupus vulgaris with vitamin D in very massive dosage is now usual only if other tuberculostatic drugs cannot be given.

Toxicology

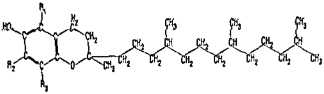
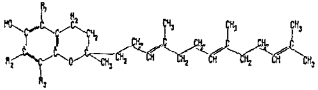
All the D vitamins are toxic in large quantities. High doses of vitamin D mobilize the bound calcium of the skeleton and bring about a considerable increase in the plasma calcium level as well as in the urinary excretion of phosphate and calcium. The calcium mobilized from the bones is taken up in the soft tissues, particularly the kidneys and media of the vessels. The clinical symptoms are loss of appetite, gastro-intestinal disturbances, pain in the head and joints and muscular weakness; in children other signs are a dry, loose skin, tremor of the limbs, loss of muscle tone with fibrillary spasms and arterial hypertension. When death occurs, this is usually due to renal failure. The symptoms of vitamin D poisoning are reversible when ingestion of the vitamin is stopped.

The toxic effect of vitamin D appears when daily doses exceed 1000–3000 IU per kg body weight and when these doses are given over several months; in infants, hypercalcaemia may appear even with total daily doses of 3000–4000 IU[21]. The clinical appearance of this idiopathic hypercalcaemia of infancy is very similar to that of vitamin D poisoning[28]. For this reason, infants and pregnant women (since idiopathic hypercalcaemia may already occur in utero) should not be given more than 400 IU vitamin D per day[21, 29]. Since enrichment of milk, margarine and baby foods with vitamin D is now quite common in many countries, the intake of this substance by infants and children is often excessive, for instance in the USA and Canada up to 2000 IU per day[21], in England up to 1200 IU per day[30].

Vitamin D_2 is less suitable for treating rickets since its hypercalcaemic effect at high dosage is greater than that of vitamin D_3. Although dihydrotachysterol has only a very slight antirachitic activity it is, like vitamin D, capable of increasing the serum calcium level. The danger of poisoning is the same, however, with both substances. In the treatment of hypercalcaemia it is essential that the serum calcium level should be watched.

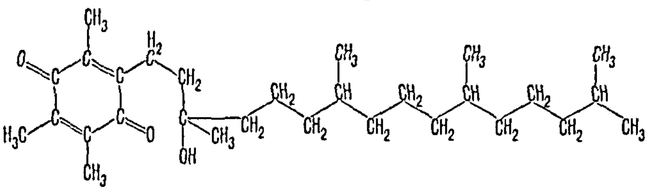
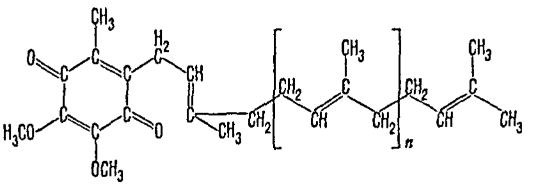
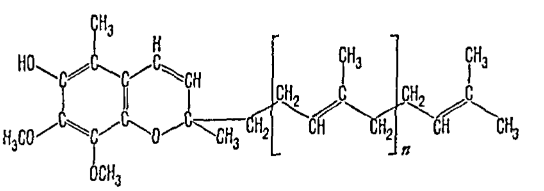
Vitamin E

Structure and properties of vitamin E and related compounds

Names*	Formula and mol wt.	Structure	Main source	Activ
		Tocols		
				
Tocol	$C_{26}H_{44}O_2$ 388 64	$R_1 = H, R_2 = H, R_3 = H$	Synthetic	Inac
8-Methyltocol (δ-tocopherol)	$C_{27}H_{46}O_2$ 402 67	$R_1 = H, R_2 = H, R_3 = CH_3$	Soybean oil	1
5,8-Dimethyltocol (β-tocopherol)	$C_{28}H_{48}O_2$ 416 69	$R_1 = CH_3, R_2 = H\ R_3 = CH_3$	Wheat-germ oil	33
7,8-Dimethyltocol (γ-tocopherol)	$C_{28}H_{48}O_2$ 416 69	$R_1 = H, R_2 = CH_3\ R_3 = CH_3$	Maize-germ oil	10
5,7,8-Trimethyl-tocol (α-tocopherol)	$C_{29}H_{50}O_2$ 430 72	$R_1 = CH_3\ R_2 = CH_3, R_3 = CH_3$	Maize-germ oil, wheat-germ oil, etc , animal tissues	100
		Tocotrienols		
				
8-Methyltoco-trienol (δ-tocotrienol)	$C_{27}H_{40}O_2$ 396 62	$R_1 = H\ R_2 = H\ R_3 = CH_3$	Palm oil	
5,8 Dimethyltoco-trienol (ε tocopherol, β-tocotrienol)	$C_{28}H_{42}O_2$ 410 65	$R_1 = CH_3\ R_2 = H\ R_3 = CH_3$	Wheat	5
7,8-Dimethyltoco-trienol (γ-tocotrienol)	$C_{28}H_{42}O_2$ 410 65	$R_1 = H\ R_2 = CH_3\ R_3 = CH_3$	Rice	
5,7,8 Trimethyl-tocotrienol (ζ₁-tocopherol, α tocotrienol, tocochromanol-3)	$C_{29}H_{44}O_2$ 424 67	$R_1 = CH_3\ R_2 = CH_3\ R_3 = CH_3$	Wheat	30

*Trivial names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the In

Structure and properties of vitamin E and related compounds (continued)

Names*	Formula and mol. wt.	Structure	Main source
		Tocopherol-like compounds	
α-Tocopheryl-quinone (α-tocopherol-quinone)	$C_{29}H_{50}O_3$ 446.72		Oxidation product of α-tocopherol, green plants
Ubiquinones (coenzymes Q)		 $n = 4–8$	Ubiquinone-9 (ubiquinone-45, coenzyme Q_9)*: leaves; ubiquinone-10 (ubiquinone-50, coenzyme Q_{10})*: liver, yeast
Ubichromenols		 $n = 5–8$	As corresponding ubiquinones

*Trivial names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the national Union of Biochemistry [*Biochim. biophys. Acta (Amst.)*, 107, 1 and 5 (1965)].
** Relative activity in antisterility test on rats.

that the process resembles the synthesis of the ubiquinones (formation of the terpenoid chain of mevalonic acid and of the aromatic ring from phenylalanine)[12].

Intake and excretion

The daily intake of adults in the USA has been estimated at 24 mg total tocopherols and 14 mg α-tocopherol[13], by another authority at 7.4 mg α-tocopherol[14]. The tocopherol esters are hydrolysed in the small intestine, and bile is necessary for their absorption. Probably only about 35% of the tocopherols in food is absorbed, the remainder being excreted in the faeces[15]. The normal concentration in adult serum is ca. 10 mg/l, in newborn infants ca. 5 mg/l (see page 609). The maximum blood level is reached 4–9 hours after giving tocopherols[16,17].

α-Tocopherol is stored in the liver and fatty tissues. High concentrations occur in the pituitary, adrenals, uterus and testes[18]. In the liver, tocopherol has been found in the mitochondria and microsomes[16]. The amount of tocopherols stored by the body is several grammes[2]. In the fatty tissues this is believed to include also α-tocopherylquinone, an oxidation product of α-tocopherol[19].

The metabolites tocopheronic acid and tocopheronolactone have been isolated in the form of glucuronides (SIMON metabolite)[20] from the urine of persons given large amounts of tocopherol.

Function

The tocopherols act as antioxidants in the following processes both in vitro and in vivo[21,22]:

(a) they prevent the oxidation of unsaturated fatty acids (linoleic acid) to peroxides; lipoperoxides are associated with the formation of the yellowish brown pigment in smooth muscle (ceroid pigment)
(b) they prevent the oxidation of vitamin A and the carotenes
(c) they prevent the oxidation of thiol groups, particularly in enzymes, presumably in conjunction with selenium[23].

The relationship between vitamin E and cholesterol metabolism is obscure[22]. The tocopherols may play a role in nucleic acid metabolism[24] and in erythropoiesis[25]. There may be a functional connection between the tocopherols and the ubiquinones, wl involved in electron transport[26], and the formation of ad triphosphate (see page 403)[27]. Vitamin E seems to have a on the transport and metabolism of vitamin B_{12}[28].

Requirements and deficiency symptoms

Healthy adults require 10–30 mg α-tocopherol per day also page 494), depending on the intake of polyene fatty a 0.6 mg α-tocopherol at least being required per gramme p fatty acid[31]. The minimal requirement of infants is probably per kg body weight[32], an amount normally absorbed with th milk.

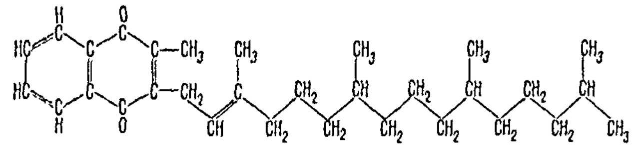
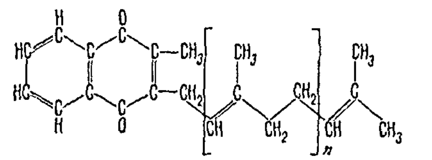
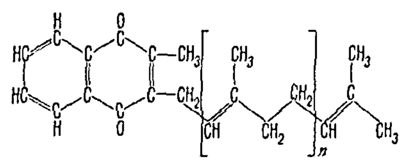
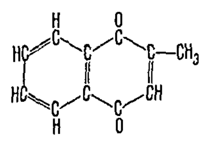
Vegetable oils are rich in tocopherols, especially wheat-g with 200–300 mg/100 g. Other good sources of tocopher cereals and eggs. Animal tissues contain little tocopherol, as α-tocopherol.

Vitamin E deficiency results in various changes depending species, age and nutritional state. They include impaired rep tivity and absorption of the foetus (rats, mice, guinea-pigs) cular dystrophy accompanied sometimes by marked crea (monkeys, mice, etc.), formation of ceroid pigments (mo mice, swine), increased haemolysis in vitro (rats, chickens), phalomalacia (chickens), exudative diathesis (chickens), ne of the liver ('respiratory decline' in rats), renal autolysis (rat

In human beings the signs of vitamin E deficiency are no marked.

A measure of the vitamin E status is provided by the pe haemolysis test[33]. In many persons a lowered serum tocop level is associated with an increase of in vitro haemolysis[30]. serum level is common in newborn infants and particularly p ture infants, and vitamin E deficiency is a possible cause of m cytic anaemia[34] and haemolytic anaemia[35] in infants. Vitar deficiency may also be caused by impaired absorption of fat Thus low tocopherol serum levels, often combined with creat and the deposition of ceroid pigments in the smooth muscle (g intestinal tract), have been observed in sprue, coeliac disease, l cirrhosis, pancreatitis and particularly cystic fibrosis of the pan A definite relationship between muscular dystrophy and vitar

Structure and properties of vitamin K and related compounds

Names*	Formula and mol. wt.	Structure	Physical properties	Occurrence	Act **
Vitamin $K_{1(20)}$ (phyllo-quinone*)	$C_{31}H_{46}O_2$ 450.71		Yellow oil M.p. −20 °C	Green plants, tomatoes, some bacteria. Isolated from alfalfa	10(
Vitamin $K_{2(30)}$ (mena-quinone-6*)	$C_{41}H_{56}O_2$ 580.90	 $n = 5$	Yellow crystals M.p. 50 °C	Isolated from putrid fishmeal	100
Vitamin $K_{2(35)}$ (mena-quinone-7*)	$C_{46}H_{64}O_2$ 649.02	 $n = 6$	Yellow crystals M.p. 54 °C	Some bacteria. Isolated from putrid fishmeal	70
Menadione (vitamin K_3, methyl-naphtho-quinone)	$C_{11}H_8O_2$ 172.19		Yellow needles M.p. 106 °C	Synthetic. Possibly a metabolite	ca. 100

* Trivial names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry [*Biochim. biophys. Acta (Amst.)*, 107, 5 (1965)].
** Relative activity in vitamin K-deficient chicks.

in some intestinal complaints like severe diarrhoea[15] and steatorrhoea[16], as well as in impaired absorption of the vitamin due to lack of bile (biliary fistula, obstruction of the bile ducts). The hypoprothrombinaemia associated with severe injury to the liver parenchyma is not due, however, to vitamin K deficiency and is also not reversed by administration of the vitamin; this forms the basis of a test of liver function. Vitamin K deficiency can also occur during long-term treatment with antibiotics or sulphonamides as a result of destruction of the intestinal flora.

During the first days of life the prothrombin activity of the plasma is 10–50% of that in adults[17], possibly because the intestinal flora is not sufficiently developed and intake of the vitamin with milk is small. Among newborn infants not given vitamin K, 0.1–1% suffer from bleeding, a proportion that has been shown to be reducible by vitamin K treatment[18,19].

Treatment

Vitamin K is given prophylactically to newborn infants, particularly premature infants and those with anoxia, the dosage of the vitamin (or of a water-soluble preparation) being 0.5–1 mg subcutaneously or intramuscularly or 1–2 mg orally at birth[18]. Double these doses may be necessary in children whose mothers have been treated with anticoagulants. Administration of the vitamin to mothers ante partum is not recommended[20]. The prophylactic use of the water-soluble menadione derivatives in pregnant women and newborn children is inadvisable on account of the danger of hyperbilirubinaemia and an increased tendency to kernicterus; these effects may be due not to the menadione derivatives themselves but to their intermediary metabolites.

The vitamin is given to correct low prothrombin activity due to a deficiency (see under 'Requirements and deficiency symptoms', above) as well as to overdosage of anticoagulants.

If possible, vitamin K should be given by the oral, intramuscul[ar] or subcutaneous route and not intravenously[21].

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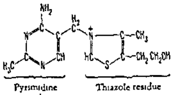
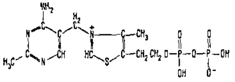
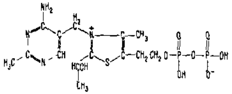
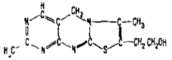
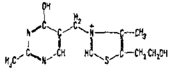
Thiamine

(For references see page 471)

nine[1-3]

re and properties of thiamine and related compounds

ompound	Formula and mol wt.	Structure	Physical properties	Occurrence and activity
mine itamin B_1, eurin)	$C_{12}H_{17}N_4OS$ (cation) 265 36 $C_{12}H_{18}N_4OSCl_2$ (hydrochloride) 337 27	 Pyrimidine residue · Thiazole residue	Colourless needles, readily soluble in water, odourless when pure, thermolabile in neutral and alkaline solution, stable to atmospheric oxygen, unstable to oxidizing agents and ultraviolet light M p. 245–248 °C (hydrochloride)	Plants In an tissues as thi mine pyroph phate
amine iphosphate TDP) amine yrophosphate TPP) ocarboxyl- se)	$C_{12}H_{18}N_4O_7P_2S$ 424 31		Pale yellow needles, readily soluble in water M.p 242–244 °C	Animal tissu Cofactor of decarboxylas and other enzymes
lydroxy- thyl 2-thia- nine diphos- hate lydroxy- thyl-2 thia- nine pyro- phosphate	$C_{14}H_{22}N_4O_8P_2S$ 468 37			Micro-organ isms, repres 60% of the t thiamine in *E. coli*[4] Alsc known as 'ac acetaldehyde (see page 39
iiochrome	$C_{12}H_{14}N_4OS$ 262 34		Yellow prisms showing blue fluorescence in solution M p. 277–278 °C	Oxidation product of thiamine
xythiamine	$C_{12}H_{16}N_3O_2S$ 266 34		M p 195–200 °C	Antagonist o thiamine

say

Biological Rat protection test, rat growth test, now little used
Microbiological Thiamine with *Ochromonas malhamensis*[5] or *Ochromonas danica*[6] pyrimidine and thiazole residues with *Saccharomyces cerevisiae*[7]
Enzymatic With apodecarboxylase from yeast[8]
Chemical[9] Quantitatively in pure solution by titration of the loride, gravimetrically as reineckate, colorimetrically via the azo rivatives from thiamine and diazonium salts, fluorimetrically th cyanogen bromide, in biological material by oxidation of thiaine to thiochrome, which shows strong blue fluorescence in ultraolet light, with suitable modifications the thiochrome method can used to determine the mono-, di- and triphosphates of thiamine well as the protein bound thiamine

Units

No international unit, by weight The former Internationa (= 0 003 mg thiamine hydrochloride = the U S Pharmac Unit) is now obsolete

Bi

'Pyrimidine residue' → (ATP) → 'Pyrimidine residue' phosphate → (ATP) → 'Pyrimidine residue' pyrophosphate

'Thiazole residue' → (ATP) → 'Thiazole residue' phosphate

'Pyrimidine residue' pyrophosphate + 'Thiazole residue' phosphate → Thiamine phosphate → Thiamine

Thiamine, but not thiamine phosphate, is converted by ATP into thiamine pyrophosphate (for instance in yeast and intestinal tissue). ATP can also convert thiamine pyrophosphate into thiamine triphosphate (yeast). On the activation of aldehydes by thiamine pyrophosphate see under 'Function', below.

Intake and excretion

In the USA, the daily diet contains about 2.15 mg thiamine[11], in Germany about 1.8 mg[12]. Thiamine is readily absorbed in the small intestine and converted enzymatically in the intestinal mucosa into thiamine pyrophosphate. In rats, thiamine is synthesized by the intestinal flora[13], but in man it is unlikely that bacterial synthesis plays an important role.

In whole blood the thiamine content is 20–75 μg/l, in serum 18–62 μg/l, in spinal fluid 3–12 μg/l[6]. Erythrocytes contain 80 μg/l, eucocytes 675 μg/l[14]. The thiamine content of the serum in newborn children is very high (see page 609). Small amounts of free thiamine are present in the serum, whereas in the erythrocytes and tissues the main component is thiamine pyrophosphate. The presence of thiamine monophosphate and triphosphate and thiochrome n the tissues has often been reported[15]. The heart muscle is fairy rich in thiamine (2–3 μg/g), as are the brain, liver and kidneys (1 μg/g); smaller quantities are present in the skeletal muscles (0.5 μg/g)[16]. The human liver contains about 4 mg of thiamine[17].

When the daily dietary intake of thiamine rises above 0.5–0.6 mg he urinary excretion of the vitamin increases in proportion to the ntake; on an ample diet it amounts to at least 100 μg/day[2,18] (see also page 676). The urine also contains breakdown products (pyimidine and thiazole residues) the amounts of which are not proportional to the thiamine content of the diet, so that they are regarded as a measure of the rate at which body stores of thiamine are being depleted[19]. The thiamine content of breast milk (see page 689) depends on the thiamine intake and shows large individual variations.

Function

Thiamine pyrophosphate possesses coenzyme functions in the breakdown of carbohydrates (oxidative decarboxylation of pyruate, see page 391), in the citric acid cycle (oxidative decarboxylation f α-ketoglutarate, see page 390), in the pentose phosphate cycle (transketolase reaction, see page 421) and other biochemical reacions[20]; at least 24 enzymes are known that contain thiamine pyro-

Reaction	Active aldehyde
Oxidative decarboxylation of pyruvate	Active pyruvate (α-lactyl-2-thiamine pyrophosphate)[21]
	Active acetaldehyde (α-hydroxyethyl-2-thiamine pyrophosphate)[21]
Oxidative decarboxylation of α-ketoglutarate	Active α-ketoglutarate (?)
	Active succinate semialdehyde (?)
Transketolase reaction	Active xylulose 5-phosphate (?)
	Active glycolaldehyde[21]
	Active sedoheptulose 7-phosphate (?)
Glyoxylate carboligase reaction	Active glyoxylate[22]
	Active formaldehyde[22]
	Active tartronic semialdehyde[22]

phosphate as coenzyme[2]. The active aldehyde group in t tions is formed or transported by thiamine pyrophosphat and is bound to the C-2 atom of the thiazole ring (see tal

Thiamine pyrophosphate plays an important part in th tion of stimuli in the peripheral nerves and in the recove after stimulation[23]; during stimulation of the periphe thiamine is liberated from thiamine pyrophosphate[24].

The thiamine-sparing effect of dietary fats probably der the fact that in thiamine deficiency the activity of pyruvate genase is more rapidly inhibited than that of oxoglutarate genase (α-ketoglutarate dehydrogenase)[2]; in thiamine d however, toxic products may also be formed from carbohy

Various synthetic compounds resembling thiamine in s such as oxythiamine, pyrithiamine and neopyrithiamin thiamine antagonists[25]; antithiamine factors of unknown occur in bacteria, plants and animals (particularly in cold animals, where the antimetabolite concerned is also k 'thiaminase')[26].

Requirements and deficiency symptoms

The requirement of thiamine depends primarily on the i carbohydrates, although in practice it is usually related to th intake. In adults the minimum requirement is about 0.27– per 1000 kcal[28]. In bottle-fed infants the maintenance dose given as 0.14–0.20 mg per day[29]. The Joint FAO/WHO Group[27] recommends a daily thiamine intake of 0.4 mg p kcal for infants, children, adults and pregnant and lactating (see page 493). The allowances of the Food and Nutritio (USA)[39] (see page 494) are based on a daily intake of 0.5 t mine per 1000 kcal. The requirement of thiamine increases metabolic rate. The possible presence of antithiamine facto diet must also be allowed for.

Good sources of thiamine are yeast, pork, liver, kidn wholemeal cereals (see pages 507–508). The vitamin is pa stroyed during cooking, particularly in alkaline media, bu affected by deep freezing[1].

The classical symptoms of vitamin B_1 deficiency are in anorexia, nausea and vomiting. Other symptoms are fatigue ness, hypotonia of the gastrointestinal tract and disturbance peripheral nerves (weakness in the limbs, hyperaesthesia and thesia, disturbances of coordination). Emotional disturban also observed, such as depression, irritability and impairm memory and power of concentration.

Beriberi takes various forms according to the predomi symptoms:

(a) An exudative form, in which oedema is the first sym This may be followed by enlargement of the heart and righ heart failure with sudden death.

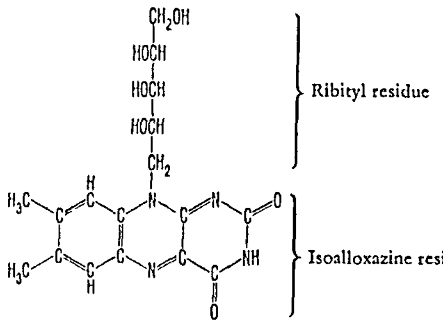
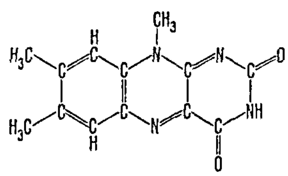
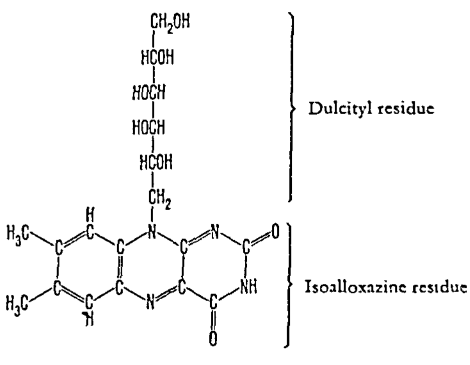
(b) A 'dry' form in which the main symptoms are polyn of peripheral degenerative type and atrophy of the muscles limbs. In European latitudes thiamine deficiency is marked by polyneuritis; it is seen for example in chronic alcoholis though this condition is probably accompanied in general b ciency of several of the B vitamins[30].

(c) A rare cerebral form with the symptoms of WERNICKE ease, namely nystagmus, ocular paralysis and emotional distur (irritability, sleeplessness, loss of memory, disorientation, co ulation, hallucinations), followed by loss of consciousnes death. This disease is seen for instance in Europe among ch alcoholics and occasionally in patients with cancer.

(d) An infantile form seen in the first year of life and a pri cause of the high infant mortality in southern and southe Asia; thus between 1954 and 1958 in the Philippines 15 000 chi died each year from beriberi[31]. The chronic form is manifeste slow growth rate, constipation, vomiting and oedema, the form by heart failure and death. Occasionally the symptoms re ble those of meningitis or encephalitis. The cause of this vit deficiency disease is still to some extent obscure. In most case mother suffers from thiamine deficiency so that the maternal is deficient in this vitamin; toxic substances in the milk may play a role[32].

Biochemically, thiamine deficiency is characterized by a low nary concentration of the vitamin (in beriberi 0–14 μg per 24 h disturbances of carbohydrate metabolism (increased blood p vate and α-ketoglutarate levels[33]) and by a low tissue concentra of thiamine pyrophosphate (erythrocytes[34], brain[35]). The thia pyrophosphate content of the erythrocytes can be measure means of the transketolase activity, which in thiamine defici can be normalized by administering thiamine pyrophospha The biochemical changes precede the pathological symptom

Structure and properties of riboflavin and related compounds

Names	Formula and mol. wt.	Structure	Physical properties	Occurrence and a(
Riboflavin (vitamin B_2, lactoflavin, 7,8-dimethyl-10-[D-ribityl]-isoalloxazine)	$C_{17}H_{20}N_4O_6$ 376.37		Orange-yellow needles, bitter taste, slightly soluble in water and ethanol, readily soluble in acids, stable to heat when dry and to acid media, very unstable to alkalis and light. Yellowish green fluorescence in solution M.p. 275–282 °C (decomp.)	Constituent of f mononucleotid flavin adenine d cleotide. Occurs free form in son micro-organism Makes up 0.5–2' of total riboflavi animal organs[4]. Present in urine
Flavinmono-nucleotide (FMN) (riboflavin-5′-phosphate)	See page 345	See page 345	Yellow powder, soluble in water	In micro-organis as active group o flavoproteins, an plants and anima Makes up 5–30% total riboflavin o animal organs[4]
Flavinadenine dinucleotide (FAD)	See page 345	See page 345	Yellow powder, readily soluble in water, insoluble in ethanol	In micro-organisr as active group of flavoproteins, and plants and animal Makes up 70–90% of riboflavin of animal organs[4]
Lumiflavin (7,8,10-tri-methyl-isoalloxazine)	$C_{13}H_{12}N_4O_2$ 256.27		Yellow crystals, only slightly soluble in water. Blue fluorescence in solution M.p. 333 °C (decomp.)	Formed from ribo flavin by irradiatic in alkaline solutio Antagonist of ribo flavin
Galactoflavin (7,8-dimethyl-10-[D-dulcityl]-isoalloxazine)	$C_{18}H_{22}N_4O_7$ 406.40		Yellow crystals, slightly soluble in water	Antagonist of ribo flavin

per day, 10% of the intake is excreted; with an intake of 1.5 mg, about 20% is excreted, with an intake of 5–11 mg, about 60%[17,19] (see also page 676). The concentration of riboflavin in breast milk depends on the intake of the vitamin[20].

Function

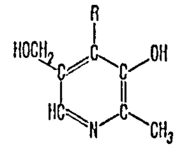
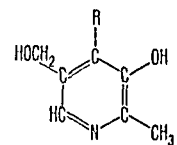
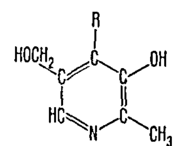
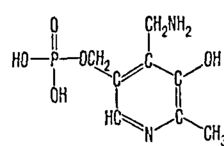
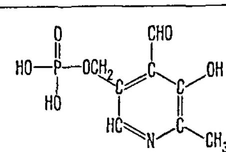
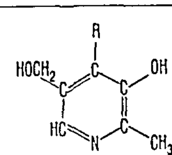
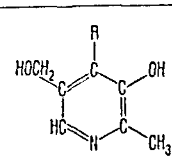
In the form of flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD) riboflavin forms the active group of the flavoproteins, enzymes with an important function in biological oxidations (see pages 402–403). Here the isoalloxazine system acts as a reversible redox system. In the oxidized form (fluorescent) the flavoproteins take up two hydrogen atoms and pass into the leuco-form (non-fluorescent); in some reactions they take up only one hydrogen atom and become semiquinones. At least 40 flavoproteins are known[21], among them (active group in brackets) import: oxidases such as aldehyde oxidase (FAD), xanthine oxidase (FAI L-amino acid oxidase (FMN), D-amino acid oxidase (FAD), c hydrogenases like acyl-CoA-dehydrogenase (FAD) and succin: dehydrogenase (FAD), NAD(P)H_2 dehydrogenases (FAD), a glutathione reductase (FAD).

Riboflavin, in combination with protein, is necessary to preve recurrent skin lesions such as those occurring in the corners of t mouth[7]. In erythropoiesis, it is possibly necessary for the formati or effective functioning of erythropoietin[22].

Requirements and deficiency symptoms

The requirement of riboflavin is usually based on the energ requirement[23] but can also be related to the protein requirement[2

Structure and properties of vitamin B_6 and related compounds

Names*	Formula and mol. wt.	Structure		Physical properties	Occurrence and
Pyridoxine*, pyridoxol* (adermine)	$C_8H_{11}NO_3$ 169.18		R = $-CH_2OH$	Colourless crystals, water-soluble, stable to heat, unstable to light M.p. 160 °C	Particularly in Vitamin B_6 act for higher plar yeasts; only sli activity for bac
Pyridoxamine*	$C_8H_{12}N_2O_2$ 168.20		R = $-CH_2NH_2$	Colourless crystals, water-soluble, unstable to heat and light M.p. 193 °C	Particularly in a tissues. Vitamir activity for mic organisms and h animals
Pyridoxal*	$C_8H_9NO_3$ 167.17		R = $-CHO$	Colourless crystals, water-soluble, unstable to heat and light	Particularly in a tissues. Vitamin activity for micr organisms and h animals
Pyridoxamine phosphate	$C_8H_{13}N_2O_5P$ 248.18			-	Coenzyme in transaminations
Pyridoxal phosphate (codecarboxylase)	$C_8H_{10}NO_6P$ 247.15			Yellow crystals, water-soluble M.p. > 270 °C	Particularly in muscle. Coenzym in decarboxylatio transaminations a phosphorylations
Pyridoxic acid (4-pyridoxic acid)	$C_8H_9NO_4$ 183.17		R = $-COOH$	White crystals, moderately soluble in water M.p. 247 °C	Particularly in uri (breakdown prod uct). No vitamin I activity
Deoxypyridoxine	$C_8H_{11}NO_2$ 153.18		R = $-CH_3$	-	Vitamin B_6 antagonist in microorganisms and animals

* Trivial names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry [*Biochim. biophys. Acta (Amst.)*, 107, 1 (1965)].

and excretion

rerage daily diet contains about 2 mg vitamin B$_6$[2]. Vitamin
iphates from foods are probably hydrolysed in the intestine
iphatases[9], and the non-phosphorylated compounds under-
orption in the upper intestinal tract. Vitamin B$_6$ is formed
the intestinal flora, though it is hardly likely that the body
use of this source of the vitamin[10]. Excretion of vitamin B$_6$

leucocytes[2] The human body can apparently convert a maxi-
of 7 mg pyridoxine per day into pyridoxal phosphate, higher
s of pyridoxine do not cause any further increase in the pyri-

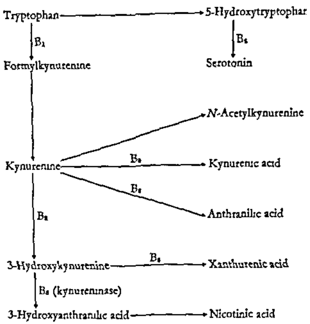
yridoxal phosphate in the body appears to be bound to α-glucan
phorylase in the muscles[16]. The daily turnover of vitamin B$_6$

ction[9 16]

itamin B$_6$ is involved as coenzyme in over 40 enzymatic re-
ons[19]. Pyridoxamine phosphate and pyridoxal phosphate act as
izymes in transamination reactions important for the break-
n of γ-aminobutyric acid in the brain and for oxalic acid met-
ism. Pyridoxal phosphate is the coenzyme in the decarboxyla-
of amino acids and for other reactions of amino acids (see
table below) Pyridoxal phosphate is also involved in various
tions of tryptophan metabolism (see figure), and this fact is
le use of in the tryptophan loading test for diagnosis of vitamin
deficiency[20] Pyridoxal phosphate is also the coenzyme in the
isport of one-carbon units from serine to tetrahydrofolic acid[21],
plays a role in the formation of circulating antibodies[22]. It is
involved with other cofactors in the synthesis of δ aminolaevu-
c acid, a precursor of the porphyrins (haemopoiesis)[23] Pyridoxal
osphate is a component of α-glucan phosphorylase[16] It is un-

Dependence of tryptophan metabolism on the B vitamins[20 26]

Bold arrows indicate the main breakdown route In vitamin B$_6$ deficiency, kynureninase is inactivated more strongly than the transaminases, which are involved in the formation of xanthurenic acid[27].



Requirements and deficiency symptoms

In adults the minimum requirement of pyridoxine hydrochlorid

the protein intake In infants it is between 0 1 and 0 5 mg per day an
is dependent on the protein intake (20 µg/g protein), the minimur
requirement of children is 0 5–1.5 mg per day, that of adolescent
1 5–2 mg per day[34]. The Food and Nutrition Board (USA) rec
ommend a vitamin B$_6$ intake of 2 0 mg per day when the dail
protein intake is 100 g or more[30]. The human vitamin B$_6$ require
ment has been the object of much discussion[31 32], it is possibl
that even higher intakes than these ...

the vitamin)[2]

The symptoms of vitamin B$_6$ deficiency vary greatly with th
species and age of the individual The great variety of deficienc
symptoms observed is in part due to the fact that in progressive E
deficiency not all the enzyme systems are blocked simultaneously t

nzymatic reactions with pyridoxamine phosphate and pyridoxal phosphate as cofactors[4]

Enzyme	Reaction	Enzyme	Reaction
Diaminoxidase, histaminase	Oxidation of diamines and histamine	Decarboxylases	For example, decarboxylation of histidine to histamine, tyrosine to tyramine, dopa to dopamine, hydroxytryptophan to serotonin
Serine hydroxymethyl transferase	Formation of 5,10-methylene tetrahydrofolic acid		
α-Glucan phosphorylase	Phosphorolysis of glycogen	Threonine aldolase	Breakdown of threonine to glycine and acetaldehyde
Transaminases	amino acid$_1$ + ketoic acid$_2$ ⇌ ketoic acid$_1$ + amino acid$_2$ (with all naturally occurring amino acids)	Dehydratases	Deamination of serine, homoserine, threonine, etc.
Synthases	Formation of tryptophan from serine and indole, of cysteine from serine, of methylcysteine from serine and methanethiol	Desulphydrases	Deaminating desulphydration of cysteine and homocysteine
		Racemases	L-amino acid ⇌ D-amino acid (alanine, methionine, glutamic acid)

the same extent[27]. The following symptoms have been observed in experimental B_6 deficiency[31]: in rats, severe dermatitis (rat pellagra), occasionally haemolytic anaemia and overall loss of body fat; in rabbits, desquamating dermatitis of the ears, mild anaemia, convulsions, creatinuria, paralytic collapse and death[35]; in rhesus monkeys, arteriosclerosis, dental caries, fatty degeneration or cirrhosis of the liver, pancreatic sclerosis, disturbances of the central nervous system[36]; in man, (a) skin and mucosa: seborrhoeic and desquamative dermatitis of the mouth and eyes which may spread to the face, scalp, neck and loins; intertrigo of the breasts and inguinal region in women; stomatitis and glossitis; (b) nervous system: irritability, depression, somnolence, nausea, impairment of sensitivity to vibration and positional change; very rarely peripheral neuritis[37].

Spontaneous vitamin B_6 deficiency is rare in man. Among 300 infants who received only about 60 µg vitamin B_6 per litre of formula milk (as a result of a new sterilization process) hyperacusis, nervousness and epileptiform convulsions were observed[38]. Of possible genetic origin are the pyridoxine-dependent convulsions ...ical or electro- ... lays of life and ... the following weeks)[38–40]; these are probably due to an unsatisfied vitamin B_6 requirement or to a disturbance of vitamin B_6 utilization. Similar causes are probably at the root of the pyridoxine-deficiency anaemia and the pyridoxine-sensitive anaemia seen in man[38, 41, 42], but in contrast to the central nervous disturbances these are observed almost solely among adults. In pyridoxine-deficiency anaemia (a hypochromic microcytic anaemia with increased serum iron and organ haemosiderosis) there is a disturbance of δ-aminolaevulinic acid synthesis, with consequent reduction in the amount of protoporphyrin formed; this disease is also probably of genetic origin. In pyridoxine-sensitive anaemia (symptoms as in the deficiency anaemia but often including enlargement of the liver and spleen) there is a complex disturbance of porphyrin metabolism resembling that in sideroachrestic anaemia.

It is uncertain whether vitamin B_6 deficiency in man causes dental caries[43] or the formation of oxalate stones in the urinary tract[44].

Cystathionuria is probably due to a defect in the linkage of the coenzyme pyridoxal phosphate to the apoenzyme of homoserine dehydratase (cystathionase)[45].

Biochemically, vitamin B_6 deficiency is recognizable (a) by the increased excretion of xanthurenic acid and other tryptophan metabolites in urine, especially following oral doses of tryptophan (tryptophan loading test)[20]; this disturbance of tryptophan metabolism appears after only one week on a vitamin B_6-deficient diet[46]; (b) by a lowered pyridoxal phosphate level in the blood and a greatly reduced vitamin B_6 and pyridoxic acid excretion in the urine[47]; (c) by a reduced transaminase content of the serum[47] and erythrocytes[48]; (d) by an increased urinary oxalic acid excretion[44, 49] and a lowered urinary taurine excretion[49].

Treatment

When the vitamin B_6 deficiency is purely alimentary, daily doses of the vitamin at the level of the normal requirement suffice. In pyridoxine-dependent convulsions in infants pyridoxine should be given parenterally at the rate of 2–15 mg per day[40]; in pyridoxine-deficiency anaemia the dose should be at least 10 mg per day[41] and in pyridoxine-sensitive anaemia at least 500 mg per day[41]. Daily pyridoxine supplements of 10–15 mg may be helpful in overcoming disturbances of pregnancy such as severe vomiting and toxaemia, particularly when the diet is poor[50]. Pyridoxine doses of 100 mg have been recommended for the treatment of radiation sickness[51]. The success of treatment with pyridoxine is conditional on there being no disturbance of the conversion into pyridoxal (by the action of pyridoxine dehydrogenase) in the body[8].

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Nicotinic acid[1–3] (for references see page 478)

Chemistry

For structure and properties of nicotinic acid and relatec pounds see the table opposite.

Assay

Biological[4]. Black tongue curative test in dogs, growth chicks.

Microbiological[5]. With *Lactobacillus plantarum* (earlier *L. arab* or *Tetrahymena pyriformis* for nicotinic acid and nicotinamide

Chemical[6]. In pure solution spectrophotometrically, polaro ically, by mass analysis, colorimetrically by the bromcya (KÖNIG) reaction or fluorometrically (the latter method partic suitable for organs). Nicotinic acid and its metabolites can b arated by chromatographic methods. NAD and NADP m hydrolysed before being determined as nicotinic acid; they c estimated directly by the spectrophotometric or fluorimetric m through their blue fluorescence in alkaline solution.

Unit

No international unit; by weight.

Biogenesis[7, 8]

In plants nicotinic acid arises by condensation of 3- and 4-c units. In animals, fungi and a few bacteria (for instance, *X monas pruni*) nicotinic acid is formed from tryptophan by the a of thiamine, riboflavin and vitamin B_6 (see diagram on page It is less likely that nicotinamide is formed directly from nic acid than by the hydrolysis of nicotinamide dinucleotides. The compounds are formed in erythrocytes, liver, yeast, etc. in a dance with the following scheme:

$$\text{cotinic acid} \xrightarrow[\text{1-pyrophosphate}]{\text{5-Phosphoribosyl}} \text{Nicotinic acid mononucleotide}$$

$\downarrow$ ATP

Nicotinic acid adenine dinucleotide (Deamido-NAD)

$\downarrow$ NH_3

$$\text{icotinamide adenine dinucleotide phosphate} \xleftarrow{\text{ATP}} \text{Nicotinamide adenine dinucleotide (NAD)}$$

ake and excretion

n the USA the daily average diet contains about 500–1000 mg ptophan and 8–17 mg nicotinic acid[9] Nicotinic acid and trypto-n are readily absorbed in the intestinal tract Nicotinic acid is

acid or tryptophan raise the dinucleotide content of the erythrocytes. In the form of dinucleotides, nicotinic acid occurs in all tissues, particularly the liver The human liver contains on the average 65 mg nicotinic acid[11].

In the liver, nicotinamide but not nicotinic acid is methylated to 1-methylnicotinamide with *S*-adenosylmethionine as methyl-

glycine (as nicotinuric acid)

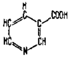
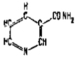
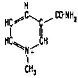
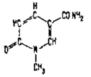
Function

The active forms of nicotinic acid are the nicotinamide dinucleotides NAD and NADP These are coenzymes (cosubstrates) of

reaction with oxygen to form water (oxidative phosphorylation), for details see pages 403–404

Nicotinic acid but not nicotinamide has an inhibiting effect at high dosage on the synthesis of lipids, particularly cholesterol, but

ucture and properties of nicotinic acid and related compounds

Compound	Formula and mol wt	Structure	Physical properties	Occurrence and activity
Nicotinic acid* (niacin, pyridine-3-carboxylic acid, vitamin PP)	$C_6H_5NO_2$ 123 11		White crystals, acid taste, moderately soluble in water and ethanol, stable to heat and oxidation M p 234–237 °C	In plant and animal tissues, component of NAD and NADP
Nicotinamide* (nicotinic acid amide, niacinamide, pyridine-3-carboxylamide, vitamin PP)	$C_6H_6N_2O$ 122 13		White crystals, salty taste, soluble in water and ethanol, stable to heat and oxidation M p 128–131 °C	In plant and animal tissues, component of NAD and NADP
1 Methylnicotinamide (N_1 methylnicotinamide)	$C_7H_9N_2O$ 137 16			In urine, metabolite of nicotinic acid
1 Methyl-6-pyridone-3-carboxylamide (N_1 methyl 2-pyridone-5-carboxylamide)	$C_7H_8N_2O_2$ 152 15		White crystals, soluble in water and ethanol M p 212–214 °C	In urine, metabolite of nicotinic acid
Nicotinamide adenine dinucleotide (NAD, reduced form $NADH_2$)	See page 344	See page 344	Colourless powder, soluble in water, insoluble in ethanol	In all animal and plant cells, coenzyme of many dehydrogenases
Nicotinamide adenine dinucleotide phosphate (NADP, reduced form $NADPH_2$)	See page 344	See page 344	Colourless powder, soluble in water, insoluble in ethanol	In all animal and plant cells, coenzyme of many dehydrogenases

* Trivial names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry (*Biochim biophys Acta (Amst)*, 107 1 (1965))

the mechanism of this effect is obscure[13]; the primary action of nicotinic acid is possibly the liberation of free fatty acids blocked in the tissues[14].

Requirements and deficiency symptoms

The nicotinic acid requirement can also be met by tryptophan, 60 mg of which corresponds to 1 mg nicotinic acid. The requirement of nicotinic acid depends on the caloric intake. The minimum requirement for preventing pellagra is 4.4 mg per 1000 kcal, or 9 mg for adults whose daily caloric intake is below 2000 kcal[9]. For children and adults the Food and Nutrition Board (USA)[9] recommend a daily intake of 6.6 mg per 1000 kcal; during pregnancy this should be increased by 2 mg per day, during lactation by 7 mg per day (see page 494). The same daily intake of 6.6 mg/1000 kcal for children and adults is recommended by the Joint FAO/WHO Expert Group[22] (see page 493); for infants the latter accept that breast feeding by well-nourished mothers will supply adequate niacin equivalents.

Good sources of nicotinic acid are yeast, liver, lean meat, groundnuts and leguminous plants (see pages 499–515). Plant proteins contain 0.8–1.4% tryptophan, animal proteins about 1.3% (see page 516). Maize is low in both nicotinic acid and tryptophan; nicotinic acid is also present in the combined form so that it is not available to the organism[15]. During the roasting of coffee considerable amounts of nicotinic acid are formed from trigonelline[16].

Nicotinic acid deficiency causes pellagra, the development of which is favoured by sunlight and heavy physical work. Alimentary nicotinic acid deficiency is common in areas where maize constitutes the principal foodstuff. Pellagra occasionally occurs in chronic alcoholism, cirrhosis of the liver, chronic diarrhoea, diabetes and neoplasias. In the presence of carcinoid tumours up to 60% (normally 1%) of the body's tryptophan is converted into serotonin, so that it is no longer available as a source of nicotinic acid[17]. Treatment with isoniazid can cause inhibition of the activity of pyridoxal phosphate and thus interfere with the synthesis of nicotinic acid from tryptophan. This synthesis is possibly also impaired by diets containing large amounts of leucine[18].

The following are the symptoms of pellagra: (a) A dark red erythema appearing symmetrically on the extremities, face, neck and all other regions exposed to air and light; the skin finally becomes dry, fissured, atrophic and brown-coloured. The lesions are marked by atrophy of the superficial layers of the corium with dilatation of the blood vessels, keratinization of the epidermis and a tendency for the latter to separate from the corium. Wounds of any kind exacerbate these symptoms. (b) Chronic inflammation of the mucosa and intestinal tract (stomatitis, glossitis, gastritis with low acid secretion); profuse and often bloody diarrhoea. (c) Emotional disturbances (delirium, hallucinations, confused mental states). Neurological disturbances, if present, are probably due to simultaneous deficiency of other vitamins since these symptoms have not been observed in experimental nicotinic acid deficiency[2].

The biochemical signs of nicotinic acid deficiency are the following: in pellagra a urinary excretion of 1-methylnicotinamide plus 1-methyl-2-pyridonecarboxylamide of usually less than 2 mg per day. Within 30–60 days the excretion of these metabolites falls to a minimum value and then remains constant; shortly after this minimum value is reached, the first clinical signs of deficiency appear[2]. On a standard diet (10 mg nicotinic acid plus 1000 mg tryptophan) the excretion of nicotinic acid metabolites is less than 3.0 mg in pellagra patients and 7–37 mg in healthy persons[19]. In nicotinic acid deficiency the concentration of nicotinamide dinucleotides in the muscles and liver falls, but not that in the erythrocytes[2, 20].

Treatment

In severe nicotinic acid deficiency, 300–500 mg nicotinamide should be given in daily oral doses of 50–100 mg; if there is difficulty in swallowing, 100 mg nicotinamide should be given three times per day intramuscularly[2]. Nicotinic acid should not be given intravenously in doses exceeding 25 mg owing to the danger of anaphylactic shock. In high doses nicotinic acid but not nicotinamide causes marked dilatation of the vessels and particularly of the capillaries and vessels of the upper half of the body; this is of therapeutic use in disturbances of the peripheral circulation. Nicotinic acid can be used to lower the serum cholesterol level and for this purpose is usually given at the rate of 1 g three times per day[21].

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(1967).

Folic acid group[1–3]

Chemistry[4]

For structure and properties of folic acid and related see the table on pages 480–481.

Assay

Biological. Curative test on chickens[5].

Microbiological[1, 6]. With *Lactobacillus casei* (total folic a pteroylglutamic acid, pteroyltriglutamic acid and hi gates, reduced folic acid including 5-methyltetrahydro tamic acid); with *Streptococcus faecalis* (pteroylglutamic a folic acid, but not 5-methyltetrahydropteroylglutamic *Pediococcus cerevisiae* (reduced folic acid). In biologic particularly foodstuffs, the conjugates can also be br enzymatically.

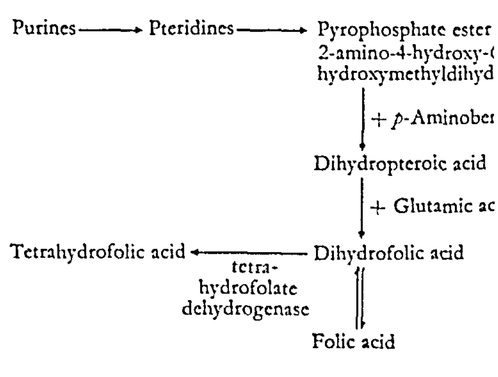
Chemical[7]. Photometrically after fission with zinc o permanganate and subsequent diazotization; in pure s spectrophotometrically or polarographically.

Units

No international unit; by weight.

Biogenesis[8]

Folic acid is synthesized by higher plants, by micro (intestinal flora) and in animal tissues[9], probably in acco the following scheme:



The biosynthesis of dihydrofolic acid is inhibited by amides[10]. Folic acid antagonists like aminopterin and with a structure resembling pyramidine (e.g., primidone methamine) inhibit tetrahydrofolate dehydrogenase and t formation of tetrahydrofolic acid.

Intake and excretion

In USA the daily diet contains about 150–200 µg activity[11, 12]; this includes only about 20 µg pteroylglutan

olic acid conjugates are hydrolysed in the upper intestinal Both the folic acid derived from the diet and that formed by testinal flora are actively absorbed in all parts of the small in-, large amounts also diffuse passively through the intestinal

, the exogenous folic acid is reduced in the tissues and stored all amounts. The total folic acid content of the human body een estimated at 12–15 mg[16], of this amount about 7 mg is ined in the liver[17]. In serum[18, 19], erythrocytes[20] and liver[21], acid is predominantly present in the form of 5-methyltetra- pteroylglutamic acid. The body's stores are probably suffi-

tion[22]

trahydrofolic acid (H_4PteGlu) is an important carrier of one- n units. These units arise mainly from histidine and serine and equired for the synthesis of purines and methionine (see the ne below and pages 433 and 436)

account of the importance of folic acid for purine and nucleic synthesis it is understandable that the vitamin should play an

uirements

e folic acid requirement is not known for certain[24]. The daily mum requirement of adults is probably about 50 µg, an amount ient to maintain the serum level[25]. Infants have a minimum irement of about 5–20 µg[26] or more[27]. The requirement is in- ed in pregnancy (possibly 200–400 µg per day in the 3rd tri- er when there is a deficiency of folate[28]). The Food and Nutri- Board (USA)[24] recommend a daily intake of 0.4 mg for adults, ng for pregnant women, and 0.5 mg for lactating women, these mounts determined in foods by *Lactobacillus casei* assay (see 494)

Good sources of folic acid are liver, kidneys, dark-green leaf vegetables, yeast (see pages 499–515). The folic acid content of fresh breast and cow's milk is sufficient to meet the requirement in infancy[29]. Folic acid is very sensitive to heat and 50–95% of the activity is destroyed by cooking.

Deficiency[30, 31]

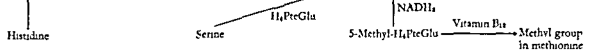
The following are causes of folic acid deficiency:

(a) Inadequate dietary intake (infants, alcoholics, cirrhotic patients)
(b) Disturbances of intestinal absorption (malabsorption syndrome, resection of the jejunum, haemochromatosis)

A daily intake of 5 µg folic acid or less results in deficiency of the vitamin[32]. The clinical symptoms are megaloblastosis of the bone marrow, microcytic anaemia, leucopenia, excessive segmentation of the leucocytes, thrombocytopenia, glossitis and gastrointestinal

Lowered serum folic acid level (< 7–16 µg/l)	2 weeks
Excessive segmentation of the leucocytes	6–10 weeks
Increased excretion of formiminoglutamic acid	12–18 weeks
Lowered erythrocyte folic acid content	17 weeks
Macroellipocytosis	18 weeks
Megaloblastosis of the bone marrow	19 weeks
Macrocytic anaemia	20 weeks

Secondary folic acid deficiency in vitamin B_{12} deficiency is probably due to blocking of tetrahydrofolic acid regeneration from 5-methyltetrahydrofolic acid, a step requiring vitamin B_{12}[13]

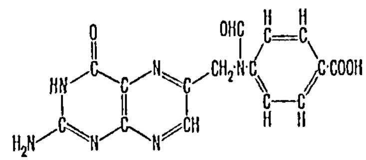
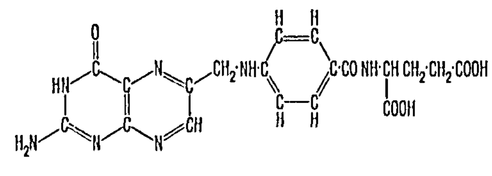
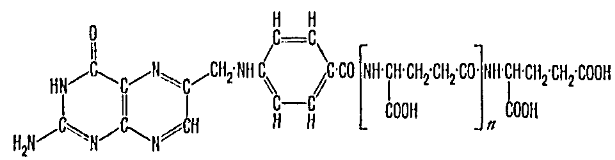
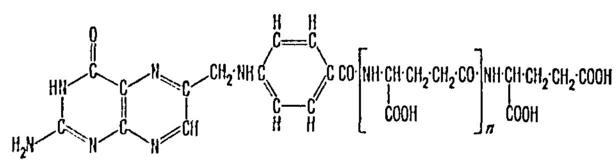
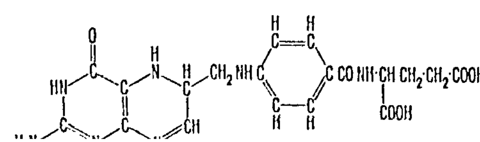


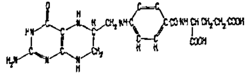
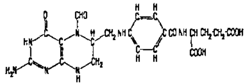
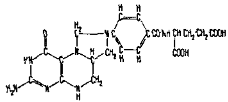
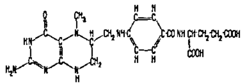
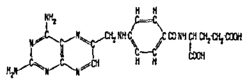
atment

ured to prevent the appearance of anaemia in patients with min B_{12} deficiency but are inadequate to protect the nervous em from *subacute degenerative changes*[24, 36]. In treatment loying folic acid antagonists (cancer) folic acid should be n in reduced form (for example as folinic acid)[37]. *During nancy*, prophylactic doses of 0.1–0.5 mg folic acid are recom- ded[16].

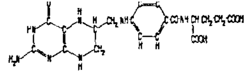
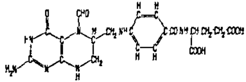
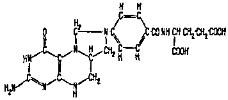
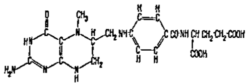
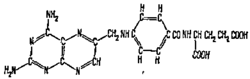
References

Structure and properties of folic acid and related compounds

Names*	Formula and mol. wt.	Structure	Physical properties	Occurrence and biological properties
Rhizopterin (SLR factor)	$C_{16}H_{12}N_6O_4$ 340.30		Light-yellow platelets	In fermentation juice of *Rhizopus nigrans*. Weak folic acid activity
Pteroylglutamic acid (folic acid, folacin, vitamin B_c, *p*-[2-amino-4-oxo-dihydropteridyl-(6)]-methylaminobenzoyl-L-glutamic acid)	$C_{19}H_{19}N_7O_6$ 441.41		Orange-yellow needles or platelets, odourless and tasteless $[\alpha]+20°$ in 0.1-N NaOH	In liver, yeast, green leaves. Growth factor for *Lactobacillus casei*, *Streptococcus faecalis R* and other micro-organisms. Anti-anaemic properties
Pteroyltriglutamic acid, $PteGlu_3$ (teropterin)	$C_{29}H_{33}N_9O_{12}$ 699.64	 $n = 2$	Light-yellow amorphous powder	In micro-organisms; formed in fermentations induced by corynebacteria. Weak folic acid activity
Pteroylheptaglutamic acid, $PteGlu_7$ (vitamin B_c conjugate)	$C_{49}H_{61}N_{13}O_{24}$ 1216.11	 $n = 6$	Orange crystals	In yeast. Microbiologically inactive; presumably the form in which pteroylglutamic acid is stored
Dihydropteroylglutamic acid, $H_2PteGlu$ (dihydrofolic acid, DHF)	$C_{19}H_{21}N_7O_6$ 443.42		Light-yellow amorphous powder	Intermediary metabolite

[illegible]tamic acid, $H_4PteGlu$ (tetrahydrofolic acid, THF)	[illegible] 445 44		powder, oxidizing in air, unstable to light, particularly in solution (-)-L-Form: $[\alpha]_D^{27} - 16\ 9°$	
5-Formyltetrahydropteroylglutamic acid (citrovorum factor, folinic acid, leucovorin)	$C_{20}H_{23}N_7O_7$ 473 45		Colourless crystals $[\alpha]_D$ -15 1° (natural factor) $[\alpha]_D^{25}$ +16 76° (racemate, synthetic factor)	In micro-organisms. Growth factor for *Leuconostoc citrovorum*, *Lactobacillus casei*, *Streptococcus faecalis*, *Lactobacillus arabinosus*, carrier of one-carbon units
5,10-Methylenetetrahydropteroylglutamic acid ('active formaldehyde')	$C_{20}H_{23}N_7O_6$ 457 45		Unstable in acid and neutral media	Carrier of one-carbon units
5 Methyltetrahydropteroylglutamic acid	$C_{20}H_{25}N_7O_6$ 459 47			In serum and liver. Carrier of one-carbon units
4-Aminopteroylglutamic acid (aminopterin)	$C_{19}H_{20}N_8O_5$ 440 42		Yellow needles	Antagonist of folic acid; inhibits cell division

* In accordance with the recommendations of the Commission on Biochemical Nomenclature of the IUPAC (IUPAC IUB Commission on Biochemical Nomenclature [*Biochim biophys Acta (Amst)*, 107, 11 (1965)] the names 'folic acid' and 'folates' should be used only as general designations for compounds of the group or mixtures of such compounds and not for any compound named on the basis of its structural formula.

tamic acid, $H_4PteGlu$ (tetrahydrofolic acid, THF)	445 44		powder, oxidizing in air, unstable to light, particularly in solution (-)-L-Form: $[\alpha]_D^{27}$ −16 9°	
5-Formyltetrahydropteroylglutamic acid (citrovorum factor, folinic acid, leucovorin)	$C_{20}H_{23}N_7O_7$ 473 45		Colourless crystals $[\alpha]_D$−15.1° (natural factor) $[\alpha]_D^{20}$+16 76° (racemate, synthetic factor)	In micro-organisms. Growth factor for *Leuconostoc citrovorum*, *Lactobacillus casei*, *Streptococcus faecalis*, *Lactobacillus arabinosus*, carrier of one-carbon units
5,10-Methylenetetrahydropteroylglutamic acid ('active formaldehyde')	$C_{20}H_{23}N_7O_6$ 457.45		Unstable in acid and neutral media	Carrier of one-carbon units
5-Methyltetrahydropteroylglutamic acid	$C_{20}H_{25}N_7O_6$ 459 47			In serum and liver. Carrier of one-carbon units
4-Aminopteroylglutamic acid (aminopterin)	$C_{19}H_{20}N_8O_5$ 440 42		Yellow needles	Antagonist of folic acid, inhibits cell division

* In accordance with the recommendations of the Commission on Biochemical Nomenclature of the IUPAC (IUPAC-IUB Commission on Biochemical Nomenclature [*Biochim biophys Acta (Amst)*, 107, 11 (1965)] the names 'folic acid' and 'folates' should be used only as general designations for compounds of the group or mixtures of such compounds and not for any compound named on the basis of its structural formula

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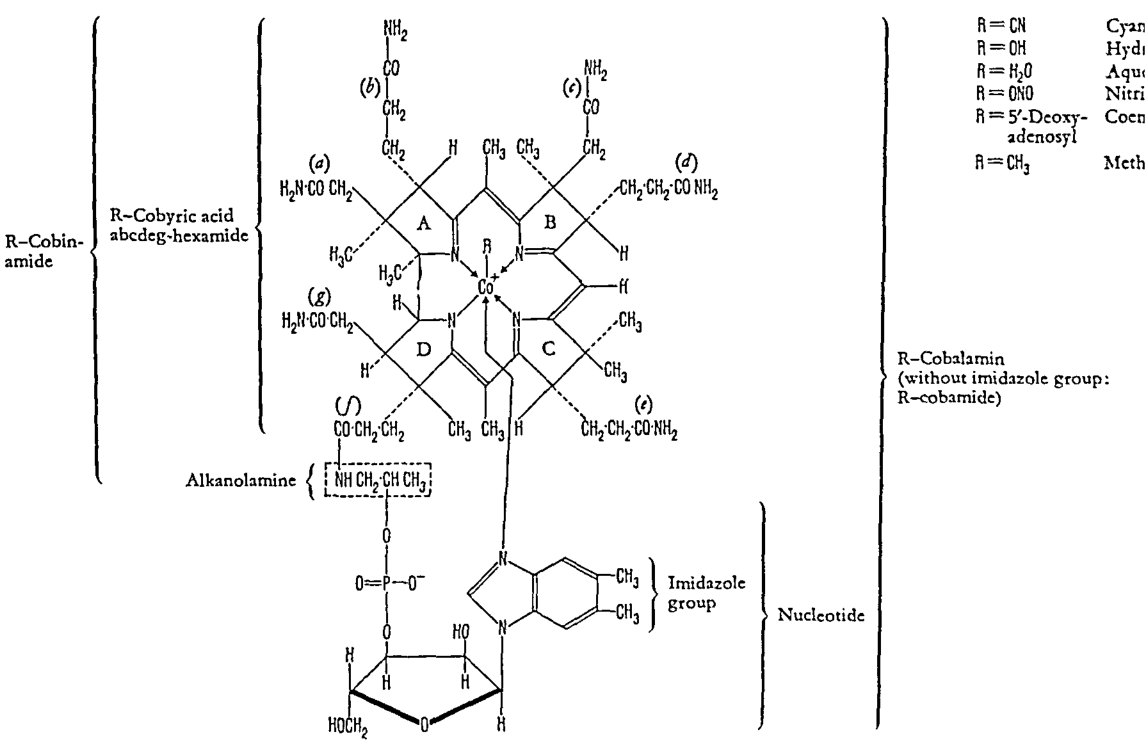
Vitamin B_{12} group (corrinoids)[1,2] (for references see page 485)

Chemistry[3]

All the complete B_{12} vitamins contain an α-glycosidic nucleotide. The imidazole nitrogen atom of this nucleotide can become co-ordinated under suitable conditions with the cobalt atom. In the case of the incomplete types either the alkanolamine and nucleotide portion, or simply the latter, is lacking; in some cases t portion is β-glycosidic, when the imidazole nitrogen become co-ordinated with the cobalt atom. The B_{12} co respond to the complete B_{12} types but in place of the ino they possess an organic group linked directly via a ca the cobalt atom. The complete and incomplete B_{12} type to light and oxygen are presumably artefacts of the B_1



Names*	Formula and mol. wt.	Physical properties	Occurrence and biological properties
		Complete B_{12} types	
Vitamin B_{12} (cyanocobalamin, 5,6-dimethylbenzimidazolylcyanocobamide)	$C_{63}H_{88}N_{14}O_{14}PCo$ 1355.40	Red needles, stable on heating several hours at 100 °C. Spectral absorption in water: maxima at 278, 361, 550 nm	Occurs in nature as coenzyme. Ca lated from animal tissues, many s bacteria, sewage sludge, activatec Stimulates maturation of erythrc bone marrow; acts as *animal prot* in animals; promotes growth (micro-organisms

* Trivial names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry anc national Union of Biochemistry [*Biochim. biophys. Acta (Amst.)*, 117, 285 (1966)].

(For references see page 485)

Names*	Formula and mol wt.	Physical properties	Occurrence and biological properties
obalamin min B_{12b}, limethylbenzimid- laquocobamide) xocobalamin min B_{12a}, limethylbenzimid- ylhydroxoco- ide)	$C_{62}H_{89}N_{13}O_{15}PCo$ 1347.39	Red needles, aquo form in neutral solution, hydroxo form in alkaline solution Spectral absorption in water: maxima at 274, 350, 522 nm	Activity as for cyanocobalamin, depot form in the human body
ylbenzimidazolyl- ocobamide		Red needles	In sewage sludge and activated sludge. Represents two-thirds of the cyanocobalamin activity in pernicious anaemia
nidazolylcyanoco- ide		Red needles	In sewage sludge and activated sludge Represents two-thirds of the cyanocobalamin activity in pernicious anaemia
roxybenzimidazolyl- iocobamide tor III)		Red needles	Inactivated sludge, weakly active in pernicious anaemia
ovitamin B_{12} ninecyano- imide)		Red needles	Inactivated sludge, faeces, stomach contents of ruminants, inactive in pernicious anaemia
hyladeninecyano- imide tor A)		Red needles	Inactivated sludge, faeces, stomach contents of ruminants, very weakly active in pernicious anaemia
		Incomplete B_{12} types	
obalamin tor B, cyanoco- imide)		Amorphous	Inactivated sludge, faeces, stomach contents of ruminants; antagonist of cayanocobalamin in the chick test
		B_{12} coenzymes	
oxyadenosylcobal- n nzyme B_{12})		Orange-yellow platelets, photosensitive	*In many species of bacteria, in animal tissues* (mainly liver) Biochemically active form of vitamin B_{12} Growth promoting-activity for micro-organisms and chicks, activity in pernicious anaemia as for cyanocobalamin, depot action in the human body
ilcobalamin		Orange-yellow platelets, photosensitive	In animal tissues (liver), blood serum. Coenzyme function

al names recommended by the Commission on Biochemical Nomenclature of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry [*Biochim biophys Acta (Amst)*, 117, 285 (1966)]

biological[1] [4] With bacteria *Escherichia coli* (cobalamins, cob- pseudo-vitamin B_{12}), *Lactobacillus leichmannii* (cobalamins, vitamin B_{12}) With protozoa *Euglena gracilis* (cobalamins, vitamin B_{12}), *Ochromonas malhamensis* (cobalamins only) *cal*[5] Spectrophotometrically or polarographically in pure , separation of the individual compounds by counter- diffusion, column chromatography or ion exchange *c dilution method* Tagging of vitamin B_{12} with ^{57}Co, ^{60}Co

Unit

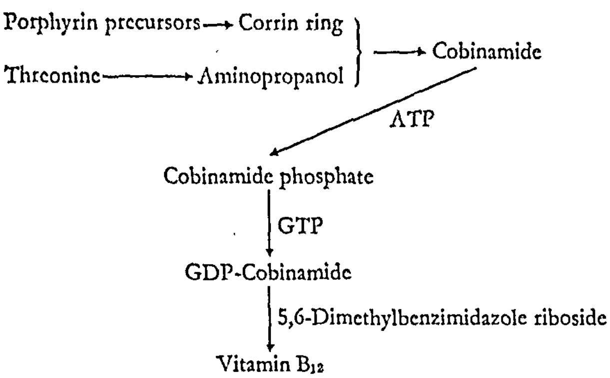
No international unit, by weight 1µg vitamin B_{12} = 11000 LLD (*Lactobacillus lactis* DORNER) Units = 1 USP Unit (liver 1 USP Unit is the daily dose that produces a clinically and logically satisfactory response in true pernicious anaemia F standpoint of activity, 1000 LLD Units corresponds to 1 ml of a good liver extract

For ... Reference Preparation see page

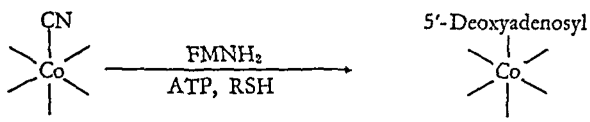
Biogenesis[6,7]

Vitamin B_{12} is synthesized by many species of bacteria, in particular the propionibacteria and *Aerobacter aerogenes*. It is possibly also formed in animal tissues[8].

The biosynthesis is in accordance roughly with the following scheme:



This process results in formation of the coenzyme forms of the vitamin; cyanocobalamin and hydroxocobalamin are probably only artefacts[9]; they can, however, be converted in animal tissues into the coenzymes:

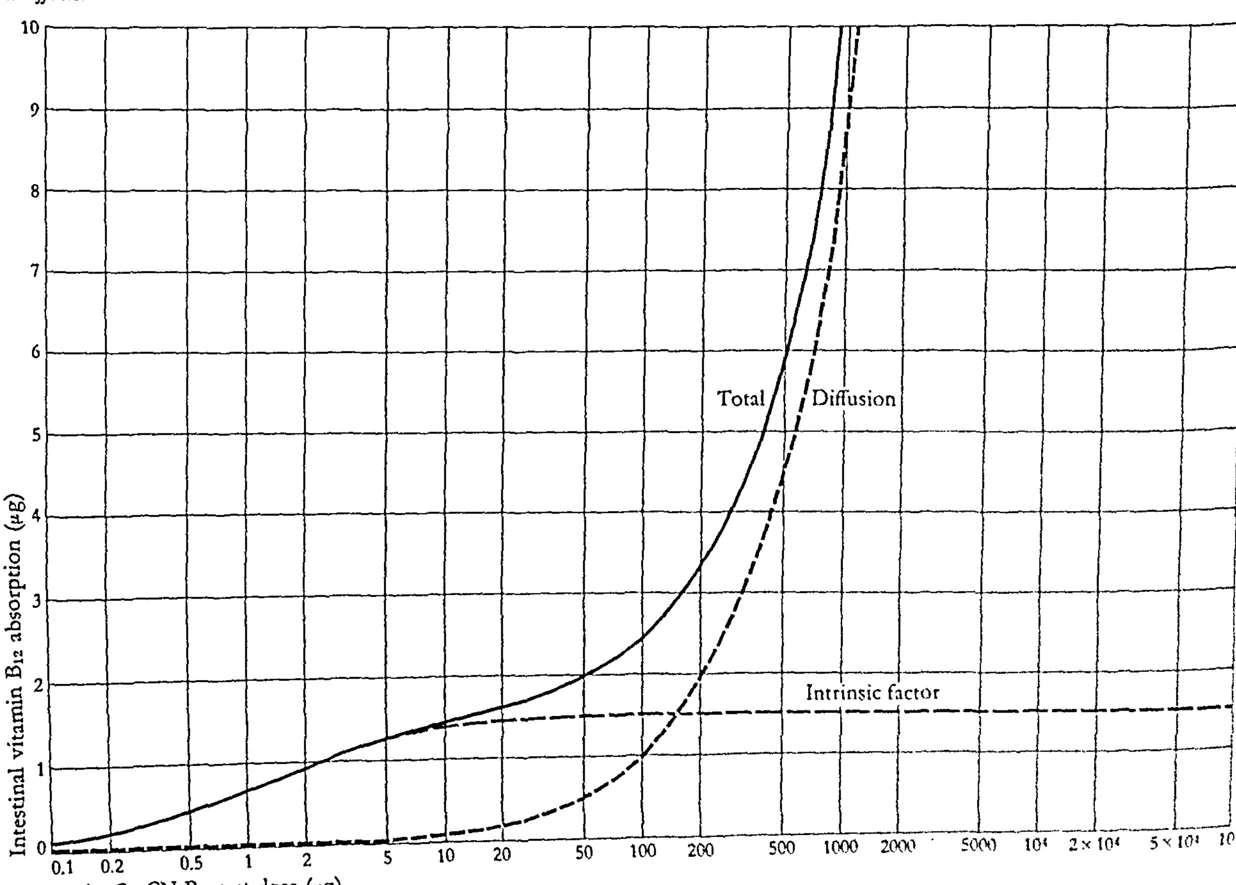


Intake and excretion

In the USA the average daily diet contains 15–30 µg vitamin B_{12}[10], of which perhaps 5 µg is absorbed. According to HEINRICH and WOLFSTELLER[12], of any dose of vitamin B_{12}, 1.5 µg is absorbed in the ileum with the aid of the so-called *intrinsic factor*, a mucoprotein of the gastric juice[11]; transport through the intestinal wall probably takes place together with the intrinsic factor[13]. In addition, there is passive diffusion through the intestinal wall[14] to an extent that increases logarithmically with increasing size of the dose up to a limiting value of 0.9% of the dose[12]. On a normal diet and three meals a day this means that 2–5 µg or more of vitamin B_{12} is absorbed daily[15] (see the figure below). Cyanocobalamin is rather more easily absorbed than coenzyme B_{12}[16]. Some 10–15 µg vitamin B_{12} is synthesized daily by bacteria in the human large intestine, and about the same quantity is excreted daily in the faeces; whether any of the quantity formed by bacterial synthesis is absorbed is doubtful[17].

The vitamin B_{12} content of the serum lies in the range 100–900 ng/l (see page 610); here the vitamin is mainly present as methylcobalamin, about 80% being bound to α-globulins (transcobalamin I). Exogenous vitamin B_{12} becomes bound for a short time to β-globulin (transcobalamin II)[18]. The half-life of intravenously administered cyanocobalamin in the serum is about 6 days[19]. Small doses of a few microgrammes of vitamin B_{12} are retained in the body but doses of a few milligrammes are rapidly excreted in the urine. Hydroxocobalamin given parenterally is retained in the body longer than cyanocobalamin or coenzyme B_{12}[16]. In the tissues the vitamin is probably stored as the coenzyme. The total body stores of the vitamin have been estimated at 2–5 mg (range 1–11 mg)[1,12,15]. The liver contains about 0.8 mg vitamin B_{12}[20] (the biological half-life of the vitamin in the liver is about 12 months[19]). 0.1% of the body's stores of vitamin B_{12} is excreted daily[15]. These stores probably suffice to prevent the appearance of clinical deficiency symptoms for 3–8 years[1,15]. Excretion of the vitamin is almost solely in the bile (see page 655), only very small amounts being found in the urine (0–0.27 µg per day)[1]. On SCHILLING's excretion test see pages 289 and 485.

Distribution of the total intestinal vitamin B_{12} absorption in healthy persons between absorption dependent on the intrinsic factor and absorption dependent on diffusion[12]



Biotin[1]

Chemistry

For structure and properties of biotin and related compounds see the table below.

Assay

Biological[3]. With *Saccharomyces cerevisiae*, *Lactobacillus casei*, *Lactobacillus arabinosus*, *Neurospora crassa*, etc.; in biological fluids preferably with *Ochromonas danica*.

Chemical. No methods in common use.

Unit

No international unit; by weight. 1 avidine unit = the smallest quantity that completely suppresses the growth-promoting effect in yeast of 1 μg biotin[4].

Biogenesis[2,5]

Biotin is synthesized in plants (particularly in sprouting seeds) and various micro-organisms. Thus *Achromobacter* forms biotin from pimelyl-coenzyme A, cysteine and carbamyl phosphate; pimelyl-coenzyme A is formed from 3 molecules of malonyl-coenzyme A[6]. The carboxyl group of biotin is covalent and bound to the lysine residue of a protein. Biocytin is formed by the action of a proteinase on protein-bound biotin.

Intake and excretion

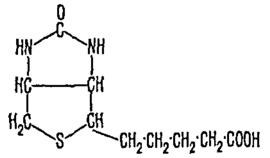
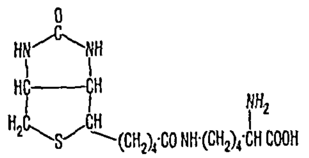
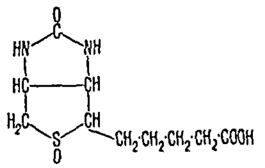
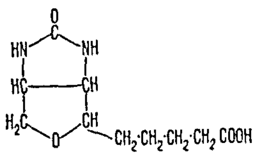
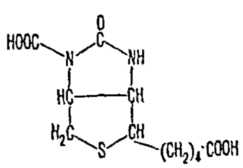
Biotin is formed by the intestinal flora in such large quantities that it is excreted in the faeces in an amount 2–5 times greater than the dietary intake[7]. The body appears to be capable of utilizing biotin formed in the intestine but to an unknown extent. The avidine present in raw egg-albumin combines with biotin, thus rendering it useless for the organism.

Biotin has been detected in whole blood and serum (see page 611) and in urine (see page 676). Small quantities are stored in the liver (about 0.2 mg) and in the brain[3,8] (blood vessels 3–5 ng/g[9]). In the liver, biotin is mostly bound to protein (in rats 90%[5]). Little is known of the metabolism of biotin. In rats given injections of biotin 16% was found 4 hours later in the liver and 30% was excreted[5].

Function[5]

Biotin is essential for warm-blooded animals and some micro-organisms. It acts as coenzyme in CO_2-fixation and transcarboxylation reactions.

Structure and properties of biotin and related compounds

Names	Formula and mol. wt.	Structure	Physical properties	Occurrence	Activity
Biotin, *d*-biotin	$C_{10}H_{16}N_2O_3S$ 244.31		White needles, stable to heat, unstable to acids and alkalis M.p. 230–232 °C $[\alpha]_D^{26}$ +91° in 0.1-N NaOH	Various micro-organisms, for example yeasts, animal tissues, particularly liver, egg-yolk, plants	Growth factor for many bacteria, protozoa and probably all higher animals
Biocytin, *d*-biocytin (ε-*N*-biotinyl-L-lysine)	$C_{16}H_{28}N_4O_4S$ 372.49		M.p. 245–252 °C	Yeasts	Growth factor for various micro-organisms
Biotin sulphoxide, *d*-biotin 1-sulphoxide (AN factor)	$C_{10}H_{16}N_2O_4S$ 260.31			Cultures of *Aspergillus niger* and *Phycomyces blakesleeanus*	Growth factor for *Neurospora crassa*
Oxybiotin (oxobiotin)	$C_{10}H_{16}N_2O_4$ 228.25		M.p. 205–207 °C		5–30% of activity of biotin[2]
1′-*N*-Carboxy-biotin (CO_2-biotin)	$C_{11}H_{16}N_2O_5S$ 288.33			Unstable intermediate	Active form of CO_2 in carboxylations

Biotin enzymes

Enzyme	Reaction catalysed	Occurrence
Acetyl-CoA-carboxylase	acetyl-CoA + HCO_3^- + ATP ⇌ malonyl-CoA + ADP + P	Micro-organisms, chicken liver
β-Methylcrotonyl CoA-carboxylase	β-methylcrotonyl-CoA + HCO_3^- + ATP ⇌ β-methylglutaconyl-CoA + ADP + P	Micro-organisms, rat liver mitochondria
Propionyl-CoA-carboxylase	propionyl CoA + HCO_3^- + ATP ⇌ methylmalonyl-CoA + ADP + P	Swine heart, ox liver mitochondria
Methylmalonyl-CoA-carboxyl-transferase	methylmalonyl-CoA + pyruvate ⇌ propionyl-CoA + oxalacetate	Propionibacteria, skeletal muscle of dogs
Pyruvate carboxylase	pyruvate + HCO_3^- + ATP ⇌ oxalacetate + ADP + P	Micro-organisms, liver mitochondria, rabbit kidneys

The carboxylation reactions catalysed by the biotin enzymes have the general form

$$\text{Biotin enzyme} + CO_2 + \text{ATP} \overset{Mg^{++}}{\rightleftharpoons} CO_2\text{-biotin enzyme} + \text{ADP} + \text{P}$$

$$CO_2\text{-biotin enzyme} + X \rightleftharpoons \text{Biotin enzyme} + CO_2\text{-}X$$

[illegible]

an important role in many other reactions in which, however, it acts only in an indirect manner. Examples of such reactions are the deamination of aspartate, serine and threonine in bacteria, deamination of serine in animals, reductive carboxylation of pyruvate, carboxylation of phosphoenol pyruvate, carbamylation reactions, tryptophan metabolism, purine synthesis, protein synthesis and carbohydrate metabolism.

Certain biotin homologues (homo-oxybiotin, biotinsulphone, in which the sulphur atom is replaced by a sulphone group) act as antivitamins[12].

Requirements and deficiency symptoms

The biotin requirement of man is unknown. In experimental biotin deficiency, doses of 150–300 µg per day sufficed to suppress the deficiency symptoms[13,14]; this amount is provided by a normal diet[15].

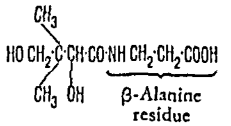
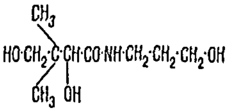
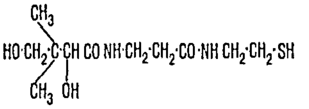
Substances rich in biotin are liver, kidneys, yeast and egg-yolk; the vitamin is also present in vegetables, nuts and cereals (see pages 498–515).

Biotin deficiency is manifested[16] in nervous disturbances (rats, pigs, chickens, man), hyperkeratosis (rats), seborrhoeic dermatitis (man), loss of hair (rats, mice), loss of hair pigment (rats, mice). Experimental biotin deficiency in man results in lethargy, loss of appetite, nausea, muscular pain and localized paraesthesia[14]. Spontaneous biotin deficiency has been reported following a diet rich in raw eggs[17,18] and also appears to be associated with liver cirrhosis[16].

Treatment

Biotin has been used to treat seborrhoeic dermatitis in young children (Leiner's disease)[19], which is possibly due to a deficiency of biotin in the breast milk together with loss of the vitamin due to persistent diarrhoea.

Structure and properties of pantothenic acid and related compounds

Compound	Formula and mol. wt.	Structure	Physical properties	Occurrence and activi
Pantothenic acid (D-[+]-*N*-[α,γ-dihydroxy-ββ-dimethylbutyryl]-β-alanine, chick antidermatitis factor)	$C_9H_{17}NO_5$ 219.24		Yellow oil, unstable to heat, acids and alkalis $[\alpha]_D^{25}+37.5°$ Calcium salt: white crystals, stable to heat	Widely distributed in plants and animals. Growth factor for ye many other micro-organisms and all higl animals; component c coenzyme A
Pantothenyl alcohol (panthenol, *N*-pantoyl-3-propanolamine)	$C_9H_{19}NO_4$ 205.26		*Viscous liquid* $[\alpha]_D^{20}+29.5°$	*Synthetic. Shows 86% of activity of pantothe acid in the chick test*[2]
Pantethein (*N*-pantothenyl-β-aminoethanethiol)	$C_{11}H_{22}N_2O_4S$ 278.37		Amorphous powder soluble in water	Growth factor for *Lactobacillus bulgaricus*
Coenzyme A (CoA)	$C_{21}H_{36}N_7O_{16}P_3S$ 767.54	See page 345	Colourless powder soluble in water	Widely distributed in micro-organisms, plants and animals. See also te and page 345

intestine, though it is not known whether the body makes use of this source. The pantothenic acid content of whole blood is ca. 0.2–2 mg/l (see page 611), that of the spinal fluid about the same (see page 639). Urinary excretion of the vitamin amounts to 0.76–4.1 mg/l[3] (see also page 676). Four hours after giving a test dose of the vitamin there is a sharp rise in the blood and urine levels[8]. In blood and spinal fluid pantothenic acid is in the conjugated form, whereas in the urine it is in the free form[3]. The excretion in the faeces is very variable and depends on the nature of the diet.

Coenzyme A is not present in the circulating blood and appears to pass the cell membrane only with difficulty. It is probably formed within the cell when required. Coenzyme A occurs mainly in the following organs (in order of decreasing concentration): liver, adrenals, kidneys, brain, heart, testes. The pantothenic acid content of the human liver amounts to 28 mg, mainly as coenzyme A[9].

Function

The importance of pantothenic acid in metabolism is explained by its presence in coenzyme A. In the form of acetyl-coenzyme A ('active acetic acid') *it is responsible for transport of two-carbon* and other acyl groups (see page 345). Coenzyme A is involved in the following reactions: formation of citrate from oxalacetate and acetate (pages 390 and 424), oxidation of pyruvate (page 391), oxidation of α-ketoglutarate (page 390), oxidation and synthesis of fatty acids (pages 391 and 424), synthesis of triglycerides (page 426), phospholipids (page 425) and cholesterol (page 426), acetylation of amines (page 444), choline (page 434) and glucosamine (see page 424). Pantothenic acid plays an important part in the activity of the adrenal cortex[10] since the corticosteroids are formed from the cholesterol synthesized with the participation of coenzyme A (page 429).

Requirements and deficiency symptoms

The human pantothenic acid requirement is unknown, but children and adults it is probably met by an intake of 5–10 mg p day[11], an amount normally present in the diet. The requirements children are lower in accordance with their smaller intake of cal ries[12].

Pantothenic acid is present in almost all vegetables, cereals a animal foods. Good sources of the vitamin are yeast, liver, kidne heart (see pages 499–515) and particularly the jelly queen bees a fed on (royal jelly), containing 110–320 μg/g[13].

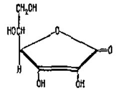
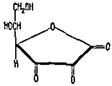
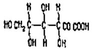
Pantothenic acid is so widely distributed in foods that deficien is practically unknown in man. Deficiency symptoms in animals a degeneration of the neuromuscular structures and adrenal insuf ciency, and death may ensue. An experimental deficiency has bee produced *in man by means of a diet low in the vitamin togeth with doses of the antagonist Ω-methylpantothenic acid*[14], with th following symptoms: mild fatigue, headache, sleeplessness, nause epigastric pain, paraesthesia of the limbs, muscle spasms and co ordination disturbances; other signs were absence of the eosino phile reaction of the blood to ACTH and an increased sensitivity t insulin. The pantothenic acid deficiency was evidenced by the re duced acetylating capacity of the blood after administration of su phanilamide or para-aminobenzoic acid.

Treatment

The so-called 'burning feet' syndrome has been tre pantothenic acid[15], though it is not certain that thi solely due to pantothenic acid deficiency. Pantot reported to be effective against the neurotoxic its value in the treatment of emotional disturb ropathy[17], skin diseases[17] and paralytic ileus

Ascorbic acid[1-3] (for references see page 491)

Chemistry

Compound	Formula and mol wt	Structure	Physical properties	Occurrence and activity
L-Ascorbic acid (vitamin C)	$C_6H_8O_6$ 176.13		White crystals with an acid taste, soluble in water, rather insoluble in ethanol, sensitive to light, atmospheric oxygen and some heavy metals, strong reducing action M p. 192 °C, $[\alpha]_D + 23°$	Probably present in all higher plants, particularly cabbage, citrus fruits, hawthorn berries, in small amounts in animal tissues Antiscorbutic activity
Dehydroascorbic acid	$C_6H_6O_6$ 174 11		White crystals, soluble in water, readily hydrolysed to 2,3-diketo-L-gulonic acid M p 225 °C	Present with ascorbic acid in plants Antiscorbutic activity
2 Keto-L-gulonic acid	$C_6H_{10}O_7$ 194 14		White crystals M p 171 °C	Precursor of ascorbic acid No antiscorbutic activity

Assay

Biological[4] In guinea pigs either by histological study of tooth

(there is some doubt as to whether these are valid for plants):

D-Glucose ⟶ D-Glucuronic acid ⟶ D-Glucuronolactone ⟶

eye 250, adrenals 400, pancreas 150, liver 150, kidneys 50, heart muscle 50. Tissue levels of ascorbic acid are highest at birth and greatly reduced in old age[12]. The saturation level in leucocytes is 270–300 mg ascorbic acid per kg[11]; high doses of ascorbic acid have been reported to increase this concentration up to 600 mg per kg[13]. The whole blood and plasma levels (see page 611) depend on the degree of tissue saturation and on the dietary intake. High doses of ascorbic acid cause the plasma level to rise rapidly, possibly to 40 mg per litre; the normal plasma level is below 14 mg per litre, since at this concentration the threshold value for the kidneys is reached with a consequent steep rise in the ascorbic acid clearance[3,11]. In the plasma about 20% of the total ascorbic acid is in the form of dehydroascorbic acid[14] (page 611). Ascorbic acid also occurs in the aqueous humour of the eye (50–295 mg/l[15]), in gastric juice (see page 650) and in the synovial fluid (see page 642).

Dependence of ascorbic acid levels in serum and leucocytes on intake[2,3,11]

Daily intake (mg)	Serum (mg/l)	Leucocytes (mg/kg)	Tissue saturation (%)	Percentage of a test dose in the urine*
<10	<2	<120	0–40	<5
10–20	~2	~120	~40	<15
30–100	4–10	150–200	>50	20–60
>100	10–14	270–300	→100	60–80

* The usual loading tests consist either of giving 10 mg ascorbic acid orally per kg body weight followed by determination of ascorbic acid in the 24-hour urine, or of giving 100 mg ascorbic acid intravenously followed by determination of ascorbic acid in the 3-hour urine.

With an ascorbic acid concentration of 20 mg per kg body weight the daily turnover is about 1 mg per kg, corresponding to a half-life of 16 days[16]. In urine ascorbic acid appears mainly unchanged (see page 676), but part is hydrolysed to diketogulonic acid and appears finally as oxalic acid[3]. Other metabolites are L-xylonic and L-lyxonic acids, which arise by decarboxylation of ascorbic acid[17]. Radioactive CO_2 has been detected in expired air after giving doses of tagged ascorbic acid[18]. The ascorbic acid content of breast milk (page 689) depends largely on the dietary intake.

Function

Ascorbic acid and dehydroascorbic acid form a redox system with 'semidehydroascorbic acid' as highly reactive intermediate. The latter arises by the loss of a single electron by ascorbic acid or by the acceptance of a single electron by dehydroascorbic acid[10]. Almost all metabolic processes the disturbance of which gives rise to scurvy involve reactions in which ascorbic acid is oxidized. Of particular importance are the hydroxylation reactions dependent on ascorbic acid which require molecular oxygen.

The disturbances in the formation of connective tissue that appear in ascorbic acid deficiency are a result of failure of the ascorbic acid-dependent hydroxylation of proline to hydroxyproline, a component of collagen. The formation and maintenance of collagen is dependent on a normal ascorbic acid level[19]. Synthesis of collagen in human skin-tissue cultures is promoted by ascorbic acid[20]. In guinea-pigs with ascorbic acid deficiency the formation of hydroxyproline in granulation tissue commences only after ascorbic acid has been administered[21].

Another hydroxylation reaction dependent on ascorbic acid is the hydroxylation of the side chain of dopamine to noradrenaline; the enzyme catalysing this reaction has been found in the microsomes of beef adrenal cortex[22]. Ascorbic acid is probably involved also in the hydroxylations occurring in steroid synthesis in the adrenals, but little is known of this role[22,23].

Ascorbic acid is also concerned in tyrosine metabolism as reducing agent, although here it does not participate in a hydroxylation reaction. Its probable effect is that of protecting the enzyme para-hydroxyphenylpyruvic acid hydroxylase from inhibition by its substrate[24]. Ascorbic acid also plays a role as electron donor in the conversion of folic acid into tetrahydrofolic acid. This connection between ascorbic acid and tetrahydrofolic acid may be responsible for the appearance of macrocytic anaemia in scurvy[10]. The hypochromic anaemia of scurvy, on the other hand, is more likely to be due to an effect of ascorbic acid on iron metabolism, since the vitamin is necessary for the incorporation of iron into ferritin[25].

In contrast to the reactions dependent on ascorbic aci hydroxylation of tryptophan to 5-hydroxytryptophan, th cursor of serotonin, is mediated by dehydroascorbic acid, wl thereby reduced to ascorbic acid. The enzyme catalysing thi tion is dependent on copper ions for its activity and occurs r in the tissues of the small intestine[26]. The regeneration of as acid from dehydroascorbic acid in the tissues plays an imp metabolic role. It takes place with the formation of semideh ascorbic acid from ascorbic acid and dehydroascorbic acid, wh an enzyme system present in the animal cell transfers electrons $NADH_2$ to semidehydroascorbic acid and so regenerates as acid[10].

In the animal organism ascorbic acid seems to have a prot action against deficiencies of other vitamins (thiamine, ribof pantothenic acid, biotin, folic acid, vitamin E, vitamin A) relationships between these vitamins and ascorbic acid are, ever, obscure[27].

Requirements and deficiency symptoms

The minimum intake of ascorbic acid required to prevent sc in infants is about 10 mg per day, in adults a little under 10 m day[28]. A daily intake of 30–40 mg results in moderate saturati the tissues, one of 60–100 mg in almost complete saturation[28]. recommended daily intakes of ascorbic acid in various coun are as follows: England[32]: infants 15 mg, children 20–30 adults 30 mg; USA[29]: infants 35 mg, children 40–80 mg, a 60 mg; Western Germany[30]: infants 30–35 mg, children 40–5 adults 75 mg; Canada[31]: children 20–30 mg, adults 30 mg; land[33]: children 35–75 mg, adults 50 mg; Japan[34]: children 3 mg, adults 60–65 mg. For the recommendations of the Food Nutrition Board (USA)[29] for pregnant and lactating womer the table on page 494. Workers in very cold climates should an intake of 150–250 mg per day[35].

Good sources of ascorbic acid are cabbage, spinach, papri citrus fruits, tomatoes, strawberries, red currants and liver pages 499–515). In vegetables the ascorbic acid falls rapidly du withering. Potatoes are an important source of ascorbic acid the concentration decreases by up to 80% in winter storage. F cow's milk contains up to 25 mg per litre; this is markedly red by pasteurization or boiling.

The most important symptoms of ascorbic acid deficiency a marked tendency to bleeding with the appearance of exten patches of haemorrhage under the skin and in the gums, mus fatty tissues and internal organs. Other symptoms are impairn of connective tissue formation with changes in bone structure growth, defective tooth formation and fissuring and rougher of the skin; there are also often disturbances of iron absorption anaemia. In infants ascorbic acid deficiency (MOELLER-BARL disease) is manifested mainly in the bones, which show a zon destroyed bone extending over the margin of the metaphysis i the soft tissues, as well as by subperiostal bleeding, particularl the metaphyseal zones of the long bones.

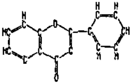
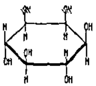
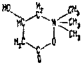
On a diet free of ascorbic acid the ascorbic acid content of plasma falls after 40 days to less than 1 mg per litre, while a 120 days that of the leucocytes is almost zero[2]. At this time ther also enlargement and keratosis of the hair follicles, which in succeeding 40 days gradually develop haemorrhages and the char teristic signs of scurvy; changes in the gingiva appear after days[36].

An inadequate intake of ascorbic acid is best recognized by lowered plasma level, whereas a severe deficiency of the vitami characterized by the low ascorbic acid concentration of the leu cytes (< 120 mg/kg; see the table above). Various tests are av able for measuring the extent to which ascorbic acid is provided the diet; they depend on the degree of tissue saturation effected b test dose of the vitamin as indicated by the plasma level and urin excretion.

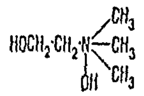
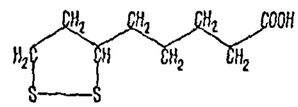
Treatment

In infants, doses of 20 mg ascorbic acid per day, for instance the form of orange juice, are ample to prevent the appearance scurvy; in infants with scurvy 25 mg should be given 4 times a d in adults with the disease 100 mg 5 or 6 times a day[28]. In patier who have undergone extensive surgery 150–300 mg ascorbic ac per day is sufficient to produce adequate saturation of the tissues The reducing properties of ascorbic acid can be utilized in the tre ment of methaemoglobinaemia and to promote the absorption orally administered iron[38]. Russian workers have reported succe in the treatment of coronary diseases with ascorbic acid[39].

Substances with vitamin-like action (vitaminoids)*

Compound	Formula, mol wt and physical properties	Occurrence	Function	Requirements and deficiency symptoms
Bioflavonoids[2] (vitamin P group, citrin)	Structure of the flavones:  Substances like hesperidine and eriodictiol also belong to this group	Widely distributed in plants, particularly in fruits (e.g., lemons and black currants)	*Biological function obscure.* Views on pharmacological activity vary. Substances increasing capillary resistance probably possess antihistamine and antihyaluronidase activity[3]	
Mesoinositol[4] (myoinositol)	 $C_6H_{12}O_6$ Mol wt 180.16 M.p. 225–227 °C	*Probable component of all living cells.* Component of phospholipids in leaves, seeds and animal tissues (particularly heart, brain and skeletal muscle), present as hexaphosphate (phytic acid) in plants	*In the phospholipid form* involved in cation transport through the cell membranes, in stimulation of nerves and in metabolism of the mitochondria[5]	*Growth factor for yeasts* and many kinds of animal cells in tissue culture. Synthesized in the animal organism. Significance in human nutrition obscure. Intake about 1 g per day
Carnitine[6] (3-hydroxy-γ-butyrobetaine, vitamin B_T)	 $C_7H_{15}NO_3$ Mol wt 161.20 $[\alpha]_D$ −20.9°	*In all animal tissues* (skeletal muscle 1, heart 0.6, kidneys 0.4, liver 0.3 mg/gramme dry substance), small amounts in blood, milk, plants and micro-organisms	*Involved in intracellular* fat metabolism in the form of acylcarnitines by (a) transporting acetyl-coenzyme A and acetoacetyl-coenzyme A from the mitochondria to the site of synthesis of long-chain fatty acids outside the mitochondria[7]; (b) transporting activated long-chain acyl groups from the cytoplasm to the mitochondria, where long-chain fatty acids are oxidized[8]	*Growth factor for some* insects, for instance mealworm, *Tenebrio molitor* and some bacterial species. Vertebrates can synthesize carnitine

* According to Braun[1] these are substances that must be *regarded as essential dietary components for* many living organisms but that do not function in the form of enzymes

Compound	Formula, mol. wt. and physical properties	Occurrence	Fu
Choline[9] (β-hydroxy-ethyltrimethyl-ammonium hydroxide)	 $C_5H_{15}NO_2$ Mol. wt. 121.18 M.p. 180 °C (decomp.)	Component of lecithin, plasmalogens, [illegible] distributed in plants and animals (egg-yolk 17, meat 6, cereals 1 mg per gramme). See also pages 394 and 434	Methyl-grou placeable by of labile met when synt the latter in volved in fatty acids f to periphera
α-Lipoic acid[11] (thioctic acid)	 $C_8H_{14}O_2S_2$ Mol. wt. 206.33 M.p. 48 °C	In small amounts in vegetable and animal tissues, particularly yeasts and liver	Involved in decarboxyl vic and acids (see 391)
Essential fatty acids[12] (vitamin F)	Linoleic and arachidonic acids (see page 370) Unsaturated fatty acids and related compounds such as the corresponding alcohols not synthesized by the body in adequate quantity but necessary for metabolism and growth	In the diet, particularly linoleic acid (plant oils, animal fats) and arachidonic acid (animal fats). Also active are linoleic acid precursors such as linoleyl alcohol and cis-2-octenic acid[13]; linolenic acid is almost inactive. Arachidonic acid is synthesized in the animal body from linoleic acid	Involved i the cell m possibly tra acids. Stru tial compo pholipids of prostagl role in met mitochond ene fatty aci leic and ar but also o effect on p pable of lo rum choles

* See footnote, page 491.

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(For references see page 497)

A *nutritional standard* is a statement of the amounts of certain nutrients (usually the average daily amounts) regarded as necessary for a person representative of the category of the population to which the standard applies[1]. Terms such as nutritional requirement and nutritional allowance are also used but must not always be regarded as synonymous. The resulting diets are referred to as minimum, average or desirable. Since it is at present impossible to define an individual's optimum requirement of any dietary constituent, other methods of evaluating nutritional standards have become necessary. In USA, the recommended dietary *allowances*[2] are

Recommended daily allowances of calories (FAO[3]) *and of vitamin A (retinol), thiamine, riboflavin and niacin** (Joint FAO/WHO Expert Group[4])

Age	Calories per day	Retinol† (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin equivalents††
0–3 months**	120 per kg	–	–	–	–
4–6 months**	110 per kg	–	–	–	–
7–12 months	1000	300	0.4	0.6	6.6
1 year	1150	250	0.5	0.6	7.6
2 years	1300	250	0.5	0.7	8.6
3 years	1450	250	0.6	0.8	9.6
4–6 years	1700	300	0.7	0.9	11.2
7–9 years	2100	400	0.8	1.2	13.9
10–12 years	2500	575	1.0	1.4	16.5
13–15 (boys)	3100	725	1.2	1.7	20.4
(girls)	2600	725	1.0	1.4	17.2
16–19 (boys)	3600	750	1.4	2.0	23.8
(girls)	2400	750	1.0	1.3	15.8
Adults (men)	3200	750	1.3	1.8	21.1
(women)	2300	750	0.9	1.3	15.2

* [illegible]

** For infants from 0 to 6 months, it is accepted that breast feeding by a well nourished mother is the best way to satisfy the nutritional requirements for these vitamins.

† For diets containing both carotene and retinol, adjustment must be made as follows: recommended intake of mixed vitamin A active compounds =

$$\frac{\text{recommended intake of retinol}}{0.167\,k + (1 - k)}, \text{ where } k = \frac{\beta\text{-carotene } (\mu g)}{\beta\text{-carotene } (\mu g) + \text{retinol } (\mu g)}$$

†† A niacin equivalent is 1 mg niacin or 60 mg L-tryptophan.

Daily protein requirements (FAO/WHO Expert Group[4])

Age	Grammes Reference Protein* per kilogramme body weight: Average	Range**
Infants		
0–3 months	2.3	–
3–6 months	1.8	–
6–9 months	1.5	–
9–12 months	1.2	–
Juveniles		
1–3 years	0.88	0.70–1.06
4–6 years	0.81	0.65–0.97
7–9 years	0.77	0.62–0.92
10–12 years	0.72	0.58–0.86
13–15 years	0.70	0.56–0.84
16–19 years	0.64	0.51–0.77
Adults††	0.59	0.47–0.71

* The composition of the Reference Protein is given on page 516. The proteins of eggs, milk and meat all have the same biological value. The intake of proteins of lower biological value must be correspondingly increased.

** This range is based on the expected range of individual variation; the upper level is likely to cover the requirements of 95% of the population [illegible]

Desirable daily calcium allowances (FAO/WHO Expert Group[5])

Age	mg/day
0–12 months*	500– 600
1–9 years	400– 500
10–15 years	600– 700
16–19 years	500– 600
Adults	400– 500
Pregnancy, 3rd trimester	1000–1200
Lactation	1000–1200

* For infants not being breast fed, the calcium requirement of an infant being breast fed by a normally lactating mother is met by the breast milk.

Calories[1]

The body requires food energy for resting metabolism, synthesis of body tissues, physical activities, excretory processes and maintenance of thermal balance. The energy requirements at different levels of activity are given in the tables on page 495.

Nutritional Standards

(For references see page 497)

*Recommended daily dietary allowances** (Food and Nutrition Board, USA[2])

	Age** (years)	Weight (kg)	Weight *(lb)*	Height cm	Height *(in)*	Calories (kcal)	Protein (g)	Minerals: Calcium (g)	Minerals: Phosphorus (g)	Minerals: Iodine (µg)	Minerals: Iron (mg)	
Infants	0–1/6	4	*9*	55	*22*	kg × 120	kg × 2.2***	0.4	0.2	25	6	
	1/6–1/2	7	*15*	63	*25*	kg × 110	kg × 2.0***	0.5	0.4	40	10	
	1/2–1	9	*20*	72	*28*	kg × 100	kg × 1.8***	0.6	0.5	45	15	
Children	1–2	12	*26*	81	*32*	1100	25	0.7	0.7	55	15	
	2–3	14	*31*	91	*36*	1250	25	0.8	0.8	60	15	
	3–4	16	*35*	100	*39*	1400	30	0.8	0.8	70	10	
	4–6	19	*42*	110	*43*	1600	30	0.8	0.8	80	10	
	6–8	23	*51*	121	*48*	2000	35	0.9	0.9	100	10	
	8–10	28	*62*	131	*52*	2200	40	1.0	1.0	110	10	
Males	10–12	35	*77*	140	*55*	2500	45	1.2	1.2	125	10	
	12–14	43	*95*	151	*59*	2700	50	1.4	1.4	135	18	
	14–18	59	*130*	170	*67*	3000	60	1.4	1.4	150	18	
	18–22	67	*147*	175	*69*	2800	60	0.8	0.8	140	10	
	22–35	70	*154*	175	*69*	2800	65	0.8	0.8	140	10	
	35–55	70	*154*	173	*68*	2600	65	0.8	0.8	125	10	
	55–75+	70	*154*	171	*67*	2400	65	0.8	0.8	110	10	
Females	10–12	35	*77*	142	*56*	2250	50	1.2	1.2	110	18	
	12–14	44	*97*	154	*61*	2300	50	1.3	1.3	115	18	
	14–16	52	*114*	157	*62*	2400	55	1.3	1.3	120	18	
	16–18	54	*119*	160	*63*	2300	55	1.3	1.3	115	18	
	18–22	58	*128*	163	*64*	2000	55	0.8	0.8	100	18	
	22–35	58	*128*	163	*64*	2000	55	0.8	0.8	100	18	
	35–55	58	*128*	160	*63*	1850	55	0.8	0.8	90	18	
	35–75+	58	*128*	157	*62*	1700	55	0.8	0.8	80	10	3
Pregnancy						+ 200	65	+0.4	+0.4	125	18	4
Lactation						+ 1000	75	+0.5	+0.5	150	18	4

		Fat-soluble vitamins: Vitamin A activity (IU)	Vitamin D (IU)	Vitamin E activity (IU)	Water-soluble vitamins: Ascorbic acid (mg)	Folacin† (mg)	Niacin†† (mEq)	Riboflavin (mg)	Thiamine (mg)	Vitamin B_6 (mg)	Vitan (µ
Infants	0–1/6	1500	400	5	35	0.05	5	0.4	0.2	0.2	1
	1/6–1/2	1500	400	5	35	0.05	7	0.5	0.4	0.3	1
	1/2–1	1500	400	5	35	0.1	8	0.6	0.5	0.4	2
Children	1–2	2000	400	10	40	0.1	8	0.6	0.6	0.5	2
	2–3	2000	400	10	40	0.2	8	0.7	0.6	0.6	2
	3–4	2500	400	10	40	0.2	9	0.8	0.7	0.7	3
	4–6	2500	400	10	40	0.2	11	0.9	0.8	0.9	4
	6–8	3500	400	15	40	0.2	13	1.1	1.0	1.0	4
	8–10	3500	400	15	40	0.3	15	1.2	1.1	1.2	5
Males	10–12	4500	400	20	40	0.4	17	1.3	1.3	1.4	5
	12–14	5000	400	20	45	0.4	18	1.4	1.4	1.6	5
	14–18	5000	400	25	55	0.4	20	1.5	1.5	1.8	5
	18–22	5000	400	30	60	0.4	18	1.6	1.4	2.0	5
	22–35	5000	–	30	60	0.4	18	1.7	1.4	2.0	5
	35–55	5000	–	30	60	0.4	17	1.7	1.3	2.0	5
	55–75+	5000	–	30	60	0.4	14	1.7	1.2	2.0	6
Females	10–12	4500	400	20	40	0.4	15	1.3	1.1	1.4	5
	12–14	5000	400	20	45	0.4	15	1.4	1.2	1.6	5
	14–16	5000	400	25	50	0.4	16	1.4	1.2	1.8	5
	16–18	5000	400	25	50	0.4	15	1.5	1.2	2.0	5
	18–22	5000	400	25	55	0.4	13	1.5	1.0	2.0	5
	22–35	5000	–	25	55	0.4	13	1.5	1.0	2.0	5
	35–55	5000	–	25	55	0.4	13	1.5	1.0	2.0	5
	55–75+	5000	–	25	55	0.4	13	1.5	1.0	2.0	6
Pregnancy		6000	400	30	60	0.8	15	1.8	+0.1	2.5	8
Lactation		8000	400	30	60	0.5	20	2.0	+0.5	2.5	6

* The allowance levels are intended to cover individual variations among most normal persons as they live in the USA under usual environmental stresses. The recommended allowances can be attained with a variety of common foods providing other nutrients for which human requirements have been less well defined.

** Entries on lines for age range 22–35 years represent the 'reference' man and woman at age 22 (see under 'Calories', page 493). All other entries represent allowances for the midpoint of the specified age range.

*** Assumes protein equivalent to human milk. For proteins not 100 utilized, factors should be increased proportionately.

† The folacin allowances refer to dietary sources as determined by *Lact bacillus casei* assay. Pure forms of folacin may be effective in doses less th: a quarter of the recommended allowance.

†† Niacin equivalents include dietary sources of the vitamin itself plus 1 mE for each 60 mg of dietary tryptophan.

Recommended daily calorie allowances (Food and Nutrition Board, USA[2]) (Light physical activity, mean environmental temperature 20 °C)

	Body weight (kg)	Body weight (*lb*)	RMR* at age 22	Age 22	Age 45	Age 65
Men	50	*110*	1540	2200	2000	1850
	55	*121*	1620	2350	2150	1950
	60	*132*	1720	2500	2300	2100
	65	*143*	1820	2650	2400	2200
	70	*154*	1890	2800	2600	2400
	75	*165*	1970	2950	2700	2500
	80	*176*	2020	3050	2800	2600
	85	*187*	2110	3200	2950	2700
	90	*198*	2210	3350	3100	2800
	95	*209*	2290	3500	3200	2900
	100	*220*	2380	3700	3400	3100
Women	40	*88*	1280	1550	1450	1300
	45	*99*	1380	1700	1550	1450
	50	*110*	1460	1800	1650	1500
	55	*121*	1560	1950	1800	1650
	58	*128*	1620	2000	1850	1700
	60	*132*	1640	2050	1900	1700
	65	*143*	1740	2200	2000	1850
	70	*154*	1830	2300	2100	1950

* RMR = resting metabolic rate, approximately 10% above the metabolic rate measured under basal conditions

Energy requirements during various activities[7]

Light work (2.5–4.9 kcal/min)	Moderately heavy work (5.0–7.4 kcal/min)	Heavy work (7.5–9.9 kcal/min)	Very heavy work (over 10 kcal/min)
Light industrial and domestic work	Farm work	Mine-working	Felling trees
Gymnastics	Marching with pack	Playing football	Steelmaking
Tile-laying	Ballroom dancing		Swimming (crawl)
Painting	Playing tennis		Climbing
Tending agricultural machines	Cycling		
Driving goods vehicles			
Playing golf, bowling			

Normal energy requirements of recumbent adults[7]

Fat (%)	Body type: Men	Body type: Women	45 kg / *99 lb*	50 / *110*	55 / *121*	60 / *132*	65 / *143*	70 / *154*	75 / *165*	80 / *176*
			Energy requirement (kcal/min)							
5–9	Lean	–	–	0.99	1.06	1.12	1.19	1.26	1.32	1.39
10–14	Average	–	–	0.94	1.01	1.09	1.14	1.21	1.28	1.34
15–19	Heavily built	Lean	0.82	0.89	0.96	1.03	1.09	1.16	1.23	1.30
20–24	Corpulent	Average	0.78	0.84	0.91	0.98	1.05	1.11	1.18	1.25
25–29	–	Heavily built	–	0.80	0.86	0.93	1.00	1.07	1.13	1.20
>30	–	Corpulent	–	–	0.81	0.88	0.95	1.02	1.08	1.15

Normal energy requirements of adults sitting and at rest[7]

Age in years	Number of subjects	Energy requirement (kcal/min): Mean	Range	s
Men (65 kg = 143 lb)				
20–39	30	1.39	0.97–1.79	0.25
40–64	30	1.37	0.87–1.94	0.29
65 and over	23	1.29	0.91–1.94	0.25
Women (55 kg = 121 lb)				
20–39	30	1.15	0.75–1.68	0.23
40–59	30	1.07	0.73–1.56	0.19
60 and over	23	1.09	0.77–1.62	0.31

Normal energy requirements of adults during walking[7]

Rate of walking km/h	mi/h	45 kg / *99 lb*	55 / *121*	65 / *143*	75 / *165*	85 / *187*	95 / *209*
		Energy requirement (kcal/min)					
3	*1.9*	2.1	2.5	2.8	3.2	3.5	3.8
4	*2.5*	2.7	3.2	3.6	4.0	4.3	4.6
5	*3.1*	3.2	3.7	4.2	4.7	5.1	5.5
6	*3.7*	3.8	4.4	4.9	5.4	5.9	6.4
7	*4.3*	4.4	5.0	5.5	6.1	6.6	7.1

unreasonably heavy clothing is worn The calorie requirement in-

this page

Protein

Dietary protein is the source of the nitrogen and essential amino

for food protein, is 0.9 g protein per kilogramme body weight per day, a value about nine times the minimum requirement of Reference Protein[4]. In the case of infants it is assumed that when lactation is normal sufficient protein is obtained from the breast milk, even though this provides little more than the minimum requirement For the protein allowances recommended by the FAO/WHO Expert Group see page 423 For premature infants the recommended allowance* is between 2.5 g and a maximum of 6 g per kilogramme body weight per day.

Carbohydrate and fat[2]

The desirable intake of carbohydrate and fat, like the optim fatty-acid composition of foods, is difficult to assess. Apart fro the body's specific needs for carbohydrate (e g , brain energy), th and fat appear to be interchangeable as dietary energy sources, a in the body they are interconvertible, except that fatty acids w an even number of C-atoms from neutral fat, etc. cannot be used form carbohydrate. Adaptation to diets very low in carbohydra is possible, but for persons accustomed to a normal diet at lea 100 g carbohydrate per day appears to be necessary if metabol disturbances like ketosis, excessive protein breakdown be avoided Normally

can be prevented by ensuring that the amount of this substance in the formula supplies 3% of the calories[10].

Essential amino acids

Of the 18 amino acids contained in food proteins 8 are essential in that the body is not capable of synthesizing them (tryptophan, phenylalanine, lysine, threonine, methionine, leucine, isoleucine, valine), 2 are semi-essential in that they are not synthesized in adequate amounts during growth (histidine, arginine), and 6 are non-essential in that the body can synthesize them from a nitrogen source such as any amino acid, ammonium salts or urea (aspartic acid, glutamic acid, proline, glycine, serine, alanine).

*Requirements of the essential amino acids**

Amino acid	Infants	Adults**		
	Minimum requirement[11] (mg/kg/day)	Minimum requirement		Recommended intake[12] (g/day)
		Young men[12] (g/day)	Young women[13] (g/day)	
L-Histidine	34	0	0	0
L-Tryptophan	22	0.25	0.16	0.50
L-Phenylalanine				
Tyrosine available†	90	0.30	0.22	–
Tyrosine not available	–	1.10	–	2.20
L-Lysine	103	0.80	0.50	1.60
L-Threonine	87	0.50	0.31	1.00
L-Methionine				
Cystine available††	45	0.20	0.35	–
Cystine not available	–	1.10	–	2.20
L-Leucine	150	1.10	0.62	2.20
L-Isoleucine	126	0.70	0.45	1.40
L-Valine	105	0.80	0.65	1.60

* Assuming that the nitrogen intake is adequate for the formation of the non-essential amino acids.
** The requirements are higher during pregnancy and lactation. The minimum requirement of men over 50 is higher than that of young men in respect of at least two amino acids (methionine 2.4–3.0 g/day, lysine 1.4–2.8 g/day)[14].
† 70–75% of the phenylalanine requirement can be met by tyrosine[12].
†† 80–90% of the methionine requirement can be met by cystine[12].

Water

The water requirement of the body is determined by the amount of heat it produces and by the load of solutes in the body fluids. It is closely linked to the intake of salt. The intake must replace water losses in the urine, faeces, sweat and insensible perspiration (skin and lungs). Under the most favourable conditions (low-solute diet, resting, no sweating) the total water supplied by the diet and metabolic processes should be at least 1.5 l/day[15]. A reasonable water allowance is 1 ml per calorie of food[2]. In hot, dry climates the water requirement can be considerably increased as a result of sweating. Under ordinary conditions, infants require proportionately more water than adults and should be given 1.5 ml per calorie of food[2].

See also 'Water and Electrolyte Balance', pages 523–530.

Sodium and chloride

The requirement of sodium and chloride is closely linked to the water balance of the body. Both the total body content and body-fluid concentration of sodium are homoeostatically controlled, moderate intakes being rapidly excreted in the urine while a reduction in intake causes excretion to drop quickly to a very low level[16]. Sodium deficiency is rare in healthy persons provided there is no abnormal loss. The normal recommended NaCl intake is 1 g per kilogramme of water[2]. Hard physical work in the tropics would require a daily intake of up to 19 g NaCl[17]. Normal diets in western Europe and USA contain 6–18 g NaCl.

Potassium

The minimum daily potassium requirement probably amounts to 0.8–1.3 g[2]. Normal diets in western countries provide 0.8–1.5 g potassium per 1000 kcal. An adequate potassium intake is important during prolonged intravenous feeding, recovery from severe diarrhoea, and diabetic acidosis; this should be met by an int 40–120 mg (1–3 mEq) per kg body weight per day.

Magnesium

The probable daily magnesium requirement[18] is 150 m children under 10 years and 200–300 mg for older children a daily protein intake of 70–80 g, men require 300–400, w 300 mg per day. The requirement seems to increase with incr protein intake. For the recommendations of the Food and N tion Board (USA) see the table on page 494. An average die vides 250–500 mg magnesium per day.

Calcium and phosphorus

Knowledge of the minimum requirements of calcium is i quate, but it is well established that no injurious effects occur the daily calcium intake lies between 300 mg and 2000 mg[19].

The desirable calcium intakes (*suggested practical allowance* commended by the FAO/WHO Expert Group (see table on 493) are lower than those of the Food and Nutrition Board (U (see table on page 494).

Although the calcium-phosphorus ratio in bone is 2:1 it is r lower in the soft tissues. This, and the fact that on a normal the intake of phosphorus always equals or exceeds that of calc have led to the recommendation[2] that the calcium and phosph allowances should be equal except in the case of young infants the table on page 494).

Iron

In order to remain in iron balance, the daily iron intake of r as well as of women after the menopause, must be 0.5–1.0 menstruating women require some 0.3–1.0 mg per day mo The iron requirement is increased during pregnancy, particu as a result of the increase in the total erythrocyte volume, and need is met partly by mobilization of iron reserves. The latte restored post partum when the total erythrocyte volume falls ag

During the first months of life the iron requirement of infan met principally from endogenous sources. Special attention sh be paid to the iron needs of growing girls, who have to meet only the requirements of growth but also cover menstruation los Assuming that 10% of the dietary iron is absorbed, the follow amounts must be available in the diet:

Dietary iron requirements (Committee on Iron Deficiency Aner American Medical Association[21])

	Iron requirement of body mg/day	Dietary ir content* mg/day
Men	0.5–1.0	5–10
Menstruating women	0.7–2.0	7–20
Pregnant women	2.0–4.8	20–48
Adolescents	1.0–2.0	10–20
Children	0.4–1.0	4–10
Infants	0.5–1.5	1.5 mg/kg

* Assuming 10% absorption of dietary iron.
** Up to a maximum of 15 mg.

With the exception of those during pregnancy, these requi ments are almost identical with the recommendation of the Fo and Nutrition Board (USA) (page 494).

Estimates of dietary iron intake in the UK, USA, Australia a Canada have given values of 10–20 mg per person per day; vario studies in the USA have shown that children aged 3–6 years hav daily iron intake of 3–11 mg[22].

In infants the iron requirement is not met by the normal inta of breast or cow's milk alone. Premature infants, as well as infa with iron deficiency, require additional iron from the 2nd to 3 month of life on; this should be given in the form of enriched cer products or possibly iron salts[23]. The iron requirement in pre nancy is likewise met only with difficulty from dietary sources.

Copper

Copper is an important component of various enzymes involv in oxygen transport. In USA and Europe the diet of adults contai an average of 1–5 mg copper per day[22]. The daily requirement adults has been estimated at 1.5–2 mg[2, 22], that of infants and ch dren at 0.04–0.14 mg per kilogramme body weight[24].

can be prevented by ensuring that the amount of this substance in the formula supplies 3% of the calories[10].

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Of the 18 amino acids contained in food proteins 8 are essential in that the body is not capable of synthesizing them (tryptophan, phenylalanine, lysine, threonine, methionine, leucine, isoleucine, valine), 2 are semi-essential in that they are not synthesized in adequate amounts during growth (histidine, arginine), and 6 are non-essential in that the body can synthesize them from a nitrogen source such as any amino acid, ammonium salts or urea (aspartic acid, glutamic acid, proline, glycine, serine, alanine).

*Requirements of the essential amino acids**

Amino acid	Infants: Minimum requirement[11] (mg/kg/day)	Adults**: Minimum requirement: Young men[12] (g/day)	Adults**: Minimum requirement: Young women[13] (g/day)	Adults**: Recommended intake[12] (g/day)
L-Histidine	34	0	0	0
L-Tryptophan	22	0.25	0.16	0.50
L-Phenylalanine				
Tyrosine available†	90	0.30	0.22	–
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* Assuming that the nitrogen intake is adequate for the formation of the non-essential amino acids.
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The requirement of sodium and chloride is closely linked to the water balance of the body. Both the total body content and body-fluid concentration of sodium are homoeostatically controlled, moderate intakes being rapidly excreted in the urine while a reduction in intake causes excretion to drop quickly to a very low level[16]. Sodium deficiency is rare in healthy persons provided there is no abnormal loss. The normal recommended NaCl intake is 1 g per kilogramme of water[2]. Hard physical work in the tropics would require a daily intake of up to 19 g NaCl[17]. Normal diets in western Europe and USA contain 6–18 g NaCl.

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Magnesium

The probable daily magnesium requirement[18] is 150 mg for children under 10 years and 200–300 mg for older children; with a daily protein intake of 70–80 g, men require 300–400, women 300 mg per day. The requirement seems to increase with increasing protein intake. For the recommendations of the Food and Nutrition Board (USA) see the table on page 494. An average diet provides 250–500 mg magnesium per day.

Calcium and phosphorus

Knowledge of the minimum requirements of calcium is inadequate, but it is well established that no injurious effects occur when the daily calcium intake lies between 300 mg and 2000 mg[19].

The desirable calcium intakes (*suggested practical allowances*) recommended by the FAO/WHO Expert Group (see table on page 493) are lower than those of the Food and Nutrition Board (USA)[2] (see table on page 494).

Although the calcium–phosphorus ratio in bone is 2:1 it is much lower in the soft tissues. This, and the fact that on a normal diet the intake of phosphorus always equals or exceeds that of calcium, have led to the recommendation[2] that the calcium and phosphorus allowances should be equal except in the case of young infants (see the table on page 494).

Iron

In order to remain in iron balance, the daily iron intake of men, as well as of women after the menopause, must be 0.5–1.0 mg; menstruating women require some 0.3–1.0 mg per day more[20]. The iron requirement is increased during pregnancy, particularly as a result of the increase in the total erythrocyte volume, and this need is met partly by mobilization of iron reserves. The latter are restored post partum when the total erythrocyte volume falls again.

During the first months of life the iron requirement of infants is met principally from endogenous sources. Special attention should be paid to the iron needs of growing girls, who have to meet not only the requirements of growth but also cover menstruation losses. Assuming that 10% of the dietary iron is absorbed, the following amounts must be available in the diet:

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	Iron requirement of body mg/day	Dietary iron content* mg/day
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Pregnant women	2.0–4.8	20–48
Adolescents	1.0–2.0	10–20
Children	0.4–1.0	4–10
Infants	0.5–1.5	1.5 mg/kg**

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Copper

Copper is an important component of various enzymes involved in oxygen transport. In USA and Europe the diet of adults contains an average of 1–5 mg copper per day[22]. The daily requirement of adults has been estimated at 1.5–2 mg[2, 22], that of infants and children at 0.04–0.14 mg per kilogramme body weight[24].

Amounts of principal nutrients, vitamins and minerals in various foods (tables on pages 499–515)

The extensive literature available on the chemical composition of foods has necessitated a critical selection of the most reliable and representative values for the various nutrients. The principal tables that have been made use of are those of the FAO[1], the US Department of Agriculture[2], the British Medical Research Council[3] and the West German Bundesministerium für Ernährung, Landwirtschaft und Forsten[4]. Data from various journals[5] have also been made use of. Detailed summaries of the nutrient contents of foods are also to be found in the works compiled by CHURCH and CHURCH[6], the Swiss Lebensmittelbuchkommission[7], RANDOIN et al.[8], SCHALL[9] and SCHTENBERG et al.[10], as well as in the monographs of ALBRITTON[11], MATTICE[12], PROUDFIT and ROBINSON[13], TURNER[14], and others.

It is important to note that the actual concentration of a particular substance in a foodstuff can deviate from the value given in the tables since all foods are subject to large variations in composition. This is particularly the case with prepared foods such as preserves, chocolate, sausages, etc. With meat, the degree of fattening of the animal plays an important part (fat content), with vegetable foods the climate, nature of the soil and degree of ripening. The storage conditions of foods affect the extent to which their water and vitamin contents are conserved. Water loss results in a higher concentration of all nutrients.

Preparing and cooking foods can lead to loss of nutrients. Some vitamins are decomposed by heat and oxidation. Both vitamins and mineral constituents pass into water in which foods are cooked and are lost if this is discarded.

The values given in the food composition tables are the contents in 100 g of the edible portion, uncooked unless otherwise stated.

With the exception of the calorific value, the data indicate the total amounts of the components in the food as ingested and not in that part of it absorbed. Little is known of the extent to which minerals and vitamins are absorbed. Thus only 2–12% – depending on the type of foodstuff – of the iron contained in foods is absorbed; the element is more readily absorbed from lean meat, haemoglobin and soya beans than from eggs, cereals and vegetables[15]. A high oxalic acid content can seriously interfere with the absorption of calcium.

The *water content* is usually determined by measuring the loss of weight at high temperature, so that the values may include other readily volatile substances.

The *protein content* is obtained from the nitrogen content by multiplying by 6.25 for meat and eggs, by 6.38 for milk, and by various factors ranging from 5.18 to 6.25 for vegetables, cereals and nuts (for details see the US Department of Agriculture Handbook No. 8[2]).

The *fat content* is that part of the food extractable by fat solvents (for instance ether). The data for polyene fatty acids are either the sum of the linoleic and arachidonic acid contents or the difference between the oleic acid and total unsaturated fatty acid contents. The cholesterol content is roughly equivalent to the unsaponifiable part of the total fat. Cholesterol occurs only in animal products, however, so that 'cholesterol' values for nuts, cereals and other vegetable foods reflect their content of other sterols.

The *carbohydrate content* is usually determined by difference, namely as the total weight less water, protein, fat and ash. Data for fibre content vary greatly with the method of determination. Collected data on the amounts of the various carbohydrates in foods are available[16].

The *calorific value* is calculated from the fat, carbohydrate and protein (and any alcoholic) content by using a specific factor that takes account of the varying extent to which different foods are absorbed (for details see the report by the Food and Agriculture Organization[17]); the data therefore represent utilizable calories.

Vitamins. Amounts of vitamin A (including β-carotene) an min D are given in international units (IU), those of all othe mins in milligrammes. 1 IU vitamin A = 0.0003 mg vitamin 0.0006 mg β-carotene; 1 IU vitamin D = 0.000025 mg vitam The data under vitamin E are α-tocopherol values (when k since this compound is responsible for most of the vitamin a (see page 465).

Percentage vitamin losses during cooking[18]

	B_1	B_2	Nicotinic acid
Meats	35	20	25
Meats plus drippings	25	5	10
Eggs	25	10	0
Cereals	10	0	10
Legumes	20	0	0
Vegetables (leafy, green and yellow)	40	25	25
Vegetables, other	25	15	25
Tomatoes	5	5	5
Potatoes	40	25	25

Zero and unknown values. Zero values are indicated by 0 througl A dash (–) denotes that the value is unknown.

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Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Poly unsaturated g	Carbohydrates: Total g	Carbohydrates: Fibre g	Calories* kcal	Vitamins: A** IU	B_1 mg	B_2 mg	B_6 mg	Nicotinic acid mg	Pantothenic acid mg	C mg	Other vitamins*** mg
Fruits, Fruit Juices															
Apples (sweet) (*Pirus malus*)	84.0	0.3	0.6	–	15.0	0.9	58	90	0.04	0.02	0.03	0.1	0.1	5[1]	E 0.3, biotin 0.001, FA 0.002
per lb as purchased (refuse 18%)	*312*	*1.1*	*2.2*	–	*56*	*3.3*	*216*	*335*	*0.15*	*0.07*	*0.11*	*0.4*	*0.4*	*19*	*E 1.1, biotin 0.004, FA 0.007*
dried	20.4	3	0.7	–	73.6	4.0	281	–	0.05	0.08	0.16	0.5	–	10[1]	–
Apple juice fresh	86.9	0.1	trace	–	13	–	47	–	0.01	0.02	0.03	0.5	0.02	1	FA 0.001, biotin 0.0005
Apple sauce, sweetened	75.7	0.2	0.1	–	23.8	0.5	91	60	0.01	0.01	–	trace	–	1	–
Apricots (*Prunus armeniaca*)	85.3	0.9	0.2	–	12.8	0.6	51	2700	0.03	0.05	0.07	0.7	0.3	7	FA 0.003
per lb as purchased (refuse 6%)	*364*	*3.8*	*0.9*	–	*55*	*2.6*	*217*	*11500*	*0.13*	*0.21*	*0.29*	*3.0*	*1.3*	*30*	*FA 0.013*
canned, sweetened	76.9	0.6	0.1	–	22.0	0.4	86	1740	0.02	0.02	0.05	0.3	0.1	4	–
dried	25.0	5.0	0.5	–	66.5	3.0	260	10900	0.01	0.16	0.25	3.3	0.7	12	FA 0.005
Avocados (*Persea gratissima*)	73.6	2.2	17.0	2	6.0	1.5	171	290	0.11	0.20	0.61	1.6	0.9	14	FA 0.03
Bananas (*Musa sapientum*)	75.7	1.1	0.2	–	22.2	0.6	85	190	0.05	0.06	0.32	0.6	0.2	10	E 0.2 biotin 0.004, FA 0.01
per lb as purchased (refuse 32%)	*233*	*3.4*	*0.6*	–	*68*	*1.9*	*262*	*586*	*0.15*	*0.19*	*1.0*	*1.9*	*6.1*	*31*	*E 0.6, biotin 0.012, FA 0.03*
Blackberries (*Rubus fruticosus*)	84.5	1.2	0.9	–	12.9	4.1	58	200	0.03	0.04	0.05	0.4	0.25	21	biotin 0.0004, FA 0.012
frozen, sweetened	74.3	0.8	0.3	–	24.4	1.8	96	140	0.02	0.10	–	0.6	–	8	–
Cantaloups (*Cucumis melo*)	91.2	0.7	0.1	–	7.5	0.3	30	3400[2]	0.04	0.03	0.036	0.6	0.26	33	biotin 0.003, FA 0.007
per lb as purchased (refuse 50%)	*207*	*1.6*	*0.2*	–	*17*	*0.7*	*68*	*7710*	*0.09*	*0.07*	*0.08*	*1.4*	*0.6*	*75*	*biotin 0.007, FA 0.016*
Cherries (*Prunus avium*)	83.4	1.2	0.4	–	14.6	0.5	60	1000	0.05	0.06	0.05	0.3	0.08	10	biotin 0.0004, FA 0.006
per lb as purchased (refuse 10%)	*340*	*4.9*	*1.6*	–	*59.6*	*2.0*	*245*	*4080*	*0.20*	*0.24*	*0.20*	*1.2*	*0.32*	*41*	*biotin 0.0016, FA 0.024*
Cranberries (*Vaccinium macrocarpon*)	87.9	0.4	0.7	–	10.8	1.4	46	40	0.03	0.02	0.06	0.1	–	12	–
Cranberry sauce	62.1	0.1	0.2	–	37.5	0.2	146	20	0.01	0.01	–	trace	–	2	–

Content per 100 grammes edible portion (unless otherwise stated)	Other organic constituents: Malic acid mg	Citric acid mg	Oxalic acid mg	Excess acid A / Excess base B	Elements: Sodium Na mg	Potassium K mg	Calcium Ca mg	Magnesium Mg mg	Manganese Mn mg	Iron Fe mg	Copper Cu mg	Phosphorus P mg	Sulphur S mg	Chlorine Cl mg
Apples (sweet) (*Pirus malus*)	270–1020	0–30	1.5	B	1	116	7	5	0.07	0.3	0.08	10	5	4
per lb as purchased (refuse 18%)	*1000–3790*	*0–112*	*5.6*	*B*	*4*	*431*	*26*	*19*	*0.26*	*1.1*	*0.29*	*37*	*19*	*15*
dried	–	–	–	B	5	557	31	29	–	1.6	–	52	19	19
Apple juice fresh	700	230	0	B	2	100	6	–	–	0.6	0.35	9	–	–
Apple sauce, sweetened	–	–	–	B	0.3	55	4	5	–	0.5	–	5	–	–
Apricots (*Prunus armeniaca*)	–	–	–	B	0.6	440	17	9	0.2	0.5	0.12	23	6	2
per lb as purchased (refuse 6%)	–	–	–	*B*	*3*	*1880*	*72*	*38*	*0.9*	*2.1*	*0.51*	*98*	*25*	*9*
canned, sweetened	330	1060	–	B	2	256	11	7	0.08	0.3	0.05	15	1.0	2
dried	810	350	–	B	26	1700	67	65	0.28	5.5	0.4	119	164	35
Avocados (*Persea gratissima*)	–	–	–	B	3	340	10	30	0.3–4.2	0.6	0.4	42	25	10
Bananas (*Musa sapientum*)	500	150	6.4	B	1	420	8	31	0.64	0.7	0.2	28	12	125
per lb as purchased (refuse 32%)	*1540*	*463*	*19.7*	*B*	*3*	*1300*	*25*	*96*	*1.97*	*2.2*	*0.6*	*86*	*37*	*386*
Blackberries (*Rubus fruticosus*)	160	trace	18	B	4	181	32	24	0.59	1.0	0.12	19	17	15
frozen, sweetened	–	–	–	B	1	105	17	12	–	0.6	–	17	–	–
Cantaloups (*Cucumis melo*)	0	–	0	B	12	230	14	17	0.04	0.4	0.04	16	11.7	41
per lb as purchased (refuse 50%)	*0*	–	*0*	*B*	*27*	*522*	*32*	*39*	*0.09*	*0.9*	*0.09*	*36*	*27*	*93*
Cherries (*Prunus avium*)	1250	10	trace	B	2	260	19	14	0.03	0.5	0.07	19	8	3
per lb as purchased (refuse 10%)	*5100*	*41*	*trace*	*B*	*8*	*1060*	*78*	*57*	*0.12*	*2.0*	*0.29*	*78*	*33*	*12*
Cranberries (*Vaccinium macrocarpon*)	260	1120	–	B	1	65	14	8	0.3	0.5	0.09	11	7	5
Cranberry sauce	–	–	–	B	1	17	6	2	–	0.2	–	4	–	–

* To convert to kJ (kilojoule) multiply the values given by 4.1855
** Vitamin A activity due to vitamin A + carotenes, 1 IU vitamin A = 0.0006 mg β-carotene
*** FA = folic acid, E = α tocopherol unless otherwise stated
[1] Wide variations between different varieties.
[2] Highly coloured variety

Content per 100 grammes edible portion (unless otherwise stated)	Water	Proteins	Fats: Total	Fats: Poly-unsaturated	Carbo-hydrates: Total	Carbo-hydrates: Fibre	Calories*	Vitamins: A**	Vitamins: B_1	Vitamins: B_2	Vitamins: B_6	Vitamins: Nicotinic acid	Vitamins: Pantothenic acid	Vitamins: C	Vitamins: Other vitamins***	Other organic constituents: Malic acid	Other organic constituents: Citric acid	Other organic constituents: Oxalic acid	Excess acid A / Excess base B	Elements: Sodium Na	Elements: Potassium K	Elements: Calcium Ca	Elements: Magnesium Mg	Elements: Manganese Mn	Elements: Iron Fe	Elements: Copper Cu	Elements: Phosphorus P	Elements: Sulphur S	Elements: Chlorine Cl
	g	g	g	g	g	g	kcal	IU	mg	mg	mg	mg	mg	mg	mg	mg	mg	mg		mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
Currants																													
red and white (*Ribes rubrum*)	85.7	1.4	0.2	–	12.1	3.4	50	120	0.04	0.02	0.05	0.3	0.06	41	biotin 0.0026	50	2300	19	B	2	275	36	15	0.6	1.0	0.12	23	29	13
black (*Ribes nigrum*)	82	1.0	0.1	–	16.1	5.7	62	220	0.05	0.03	0.08	0.3	–	136	–	400	3030	4	B	3	336	17	10	–	0.9	0.12	28	–	–
Dates (*Phoenix dactylifera*)																													
dried	22.5	2.2	0.5	–	72.9	2.3	274	50	0.09	0.10	0.1	2.2	0.8	0	FA 0.025	–	–	–	B	1	790	59	65	0.15	3.0	0.21	63	65	290
Elderberries, black (*Sambucus nigra*)	80.9	2.5	0.5	–	15.9	6.8	42	600	0.07	0.08	0.25	1.5	0.18	18	biotin 0.002; FA 0.017	–	–	–	B	0.5	305	35	–	–	1.6	–	57	–	–
Figs (*Ficus carica*)	81.7	1.2	0.4	–	16.1	1.4	65	75	0.09	0.08	0.13	0.63	0.4	2	FA 0.01	trace	340	–	B	2	190	35	21	–	0.8	0.06	22	12	14
dried	23.0	4.3	1.3	–	69.1	5.6	274	80	0.10	0.10	0.32	1.7	0.5	0	FA 0.03	–	–	–	B	34	780	126	82	0.35	4.0	0.35	116	69	105
Fruit cocktail																													
canned	79.6	0.4	0.1	–	19.7	0.4	76	140	0.02	0.01	–	0.4	–	2	–	–	–	–	B	5	160	9	8	–	0.4	0.03	12	2	3
Gooseberries (*Ribes grossularia*)	88.9	0.8	0.2	–	9.7	1.9	39	290	0.15	0.03	0.02	0.3	0.15	25	biotin 0.0005	500–2080	–	–	B	1	210	35	9	0.04	0.5	0.08	31	15	9
Grapes (*Vitis vinifera*)	81.4	0.6	0.3	–	17.3	0.5	67	100	0.05	0.02	0.1	0.3	0.08	4	biotin 0.002; FA 0.006	650	–	–	B	2	250	12	7	0.083	0.4	0.1	20	9	2
Grape juice	82.9	0.2	trace	–	16.6	trace	66	–	0.04	0.02	0.021	0.2	0.04	2	biotin 0.0003; FA 0.003	310	20	–	B	1	120	11	4	–	0.3	0.02	12	–	–
Grapefruit (*Citrus decumana*)	88.4	0.6	0.1	–	9.8	0.5	39	80	0.04	0.02	0.02	0.2	0.25	40	E 0.25; FA 0.003; biotin 0.003	80	1460	0	B	2	198	17	10	0.01	0.3	0.02	16	5	3
per lb as purchased (refuse 51%)	*197*	*1.3*	*0.2*	–	*22*	*1.1*	*87*	*178*	*0.09*	*0.04*	*0.04*	*0.4*	*0.56*	*89*	*E 0.56; FA 0.007; biotin 0.007*	*178*	*3250*	*0*	*B*	*5*	*441*	*38*	*22*	*0.02*	*0.7*	*0.04*	*36*	*11*	*7*
canned, sweetened	81.1	0.6	0.1	–	17.8	0.2	70	10	0.03	0.02	–	0.2	–	30	–	–	–	–	B	2	135	13	11	–	0.3	–	14	–	–
Grapefruit juice, fresh	89.2	0.4	0.1	–	9.8	0.1	41	10	0.03	0.02	0.014	0.2	0.16	45	biotin 0.0007; FA 0.001	–	–	–	B	2	150	8	12	–	0.4	–	14	5	2
Lemons (*Citrus medica*)	90.1	1.1	0.3	–	8.2	0.4	27	20	0.04	0.02	0.06	0.1	0.2	45	FA 0.007	trace	3840	–	B	6	148	26	9	0.04	0.6	0.26	16	8	4
Lemon juice	91.0	0.5	0.2	–	8.0	–	25	20	0.03	0.01	0.039	0.1	0.1	50	FA 0.001	290	6080	–	B	1	130	14	7	–	0.2	0.13	11	2	4
Lime juice (*Citrus aurantifolia*)	90.3	0.3	–	–	9.0	–	26	10	0.02	0.01	0.05	0.1	–	32	–	–	–	–	B	1	100	9	–	–	0.2	–	11	–	39
Loganberries (*Rubus ursinus* var. *loganobaccus*)	83	1.0	0.6	–	14.9	3.0	62	200	0.03	0.04	–	0.4	–	24	–	–	–	–	B	1	170	35	25	–	1.2	0.14	17	18	16
Melons, water (*Citrullus vulgaris* var. *colocynthoides*)	92.6	0.5	0.2	–	6.4	0.3	26	590	0.03	0.03	0.033	0.2	0.3	7	biotin 0.004; FA 0.0006	200	–	0	B	0.3	100	7	8	0.02	0.5	0.07	10	9	8
Nectarines (*Prunus persica* var. *nectarina*)	81.8	0.6	trace	–	17.1	0.4	64	1650	–	–	–	–	–	13	–	–	–	–	B	6	294	4	13	–	0.5	0.06	24	10	5

* To convert to kJ (kilojoule) multiply the values given by 4.1855. ** Vitamin A activity due to vitamin A

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Polyunsaturated g	Carbohydrates: Total g	Carbohydrates: Fibre g	Calories* kcal	Vitamins: A** IU	B_1 mg	B_2 mg	B_6 mg	Nicotinic acid mg	Pantothenic acid mg	C mg	Other vitamins*** mg	Constituents: Malic acid mg	Citric acid mg	Oxalic acid mg	Excess acid A / Excess base B	Sodium Na mg	Potassium K mg	Calcium Ca mg	Magnesium Mg mg	Manganese Mn mg	Iron Fe mg	Copper Cu mg	Phosphorus P mg	Sulphur S mg	Chlorine Cl mg
Olives (*Olea europaea*) green	78.2	1.4	12.7	1.0	1.3	1.3	116	300	0.03	0.08	0.02	0.5	0.02	0	FA 0.001	–	–	–	B	2400	55	61	22	0.05–1.0	1.6	0.46	17	32	3750
Oranges (*Citrus sinensis*)	87.1	1.0	0.2	–	12.2	0.5	49	200	0.10	0.03	0.03	0.2	0.2	50	E 0.23, biotin 0.001, FA 0.005	trace	980	24	B	0.3	170	41	10	0.025	0.4	0.07	23	8	4
per lb as purchased (refuse 27%)	*288*	*3.3*	*0.7*	–	*40*	*1.7*	*162*	*662*	*0.33*	*0.10*	*0.10*	*0.7*	*0.7*	*166*	*E 0.76, biotin 0.003, FA 0.017*	*trace*	*3250*	*79*	*B*	*1*	*563*	*136*	*33*	*0.083*	*1.3*	*0.23*	*76*	*26*	*13*
Orange juice, fresh	86	0.6	0.1	–	12.9	0.1	49	100	0.07	0.02	0.026	0.2	0.14	50†	biotin 0.0003, FA 0.002	–	–	–	B	0.5	190	11	11	–	0.3	0.08	17	8	4
Peaches (*Prunus persica*)	86.6	0.6	0.1	–	11.8	0.6	46	880	0.02	0.05	0.02	1.0	0.12	7	biotin 0.002, FA 0.004	370	370	trace	B	0.5	160	9	10	0.11	0.5	0.01	19	7	5
per lb as purchased (refuse 13%)	*342*	*2.4*	*0.4*	–	*47*	*2.4*	*182*	*3470*	*0.08*	*0.20*	*0.08*	*3.9*	*0.5*	*28*	*biotin 0.008, FA 0.016*	*1460*	*1460*	*trace*	*B*	*2*	*631*	*36*	*39*	*0.43*	*2.0*	*0.04*	*74*	*28*	*20*
canned, sweetened	79.1	0.4	0.1	–	20.1	0.4	78	430	0.01	0.02	0.02	0.6	0.05	4	biotin 0.0002, FA 0.0005	–	–	1.2	B	5	107	4	6.3	0.04	0.3	0.06	12	1	4
dried	25.0	3.0	0.7	–	68.3	3.1	262	3900	0.01	0.2	0.15	5.3	–	18	–	–	–	–	B	12	1100	48	54	0.67	6.0	0.3	117	240	11
Pears (*Pirus communis*)	83.2	0.5	0.4	–	15.5	1.5	61	20	0.02	0.04	0.02	0.1	0.05	4	biotin 0.0001, FA 0.002	120	240	3	B	2	129	8	9	0.06	0.3	0.13	11	7	4
per lb as purchased (refuse 9%)	*349*	*2.1*	*1.7*	–	*64*	*6.2*	*252*	*83*	*0.08*	*0.17*	*0.08*	*0.4*	*0.21*	*17*	*biotin 0.0004, FA 0.008*	*495*	*991*	*12*	*B*	*8*	*532*	*33*	*37*	*0.25*	*1.2*	*0.54*	*46*	*29*	*17*
canned, sweetened	79.8	0.2	0.2	–	19.6	0.6	76	trace	0.01	0.02	–	0.1	0.02	1	–	160	420	1.7	B	2	52	5	6	–	0.2	0.04	7	1.3	3
Persimmons, Japanese (kaki) (*Diospyros kaki*)	78.8	0.7	0.4	–	19.7	1.6	77	2710	0.03	0.02	–	0.1	–	11	–	–	–	–	B	6	174	6	8	–	0.3	–	26	–	–
Pineapples (*Ananas sativus*)	86.7	0.4	0.2	–	12.2	0.5	47	70	0.08	0.03	0.08	0.2	0.17	17	FA 0.004	120	770	–	B	0.3	210	17	17	1.07	0.5	0.07	8	2.5	46
canned, sweetened	79.9	0.3	0.1	–	19.4	0.3	74	50	0.08	0.02	0.07	0.2	–	7	FA 0.001	–	–	6.3	B	1	120	11	8	–	0.3	0.05	5	2.7	4.2
Pineapple juice, canned	85.6	0.4	0.1	–	13.5	0.1	55	50	0.05	0.02	0.1	0.2	0.1	7	FA 0.001	–	–	–	B	1	140	15	15	–	0.5	–	9	–	–
Plums (*Prunus domestica*)	85.7	0.7	0.1	–	12.3	0.7	50	250	0.07	0.04	0.05	0.5	0.13	6	biotin trace, FA 0.002	360–2390	30	10	B	2	167	13	13	0.1	0.4	0.3	23	5	2
per lb as purchased (refuse 6%)	*365*	*3.0*	*0.4*	–	*52*	*3.0*	*213*	*1070*	*0.30*	*0.17*	*0.21*	*2.1*	*0.55*	*26*	*biotin trace, FA 0.008*	*1540–10200*	*128*	*43*	*B*	*8*	*712*	*55*	*55*	*0.4*	*1.7*	*1.3*	*98*	*21*	*8*
canned, sweetened	77.4	0.4	0.1	–	21.6	0.3	83	230	0.02	0.02	0.027	0.4	0.08	2	FA 0.001	–	–	–	B	1	142	9	5	0.07	0.9	0.16	10	–	–
Prunes dried, uncooked	28.0	2.1	0.6	–	67.4	1.6	255	1600	0.1	0.17	0.5	1.6	0.35	3	FA 0.005	–	–	–	B	6	700	51	32	0.18	3.9	0.16	79	28	9
Quinces (*Cydonia oblonga, Cydonia vulgaris*)	84	0.3	0.3	–	14.9	2.4	57	30	0.03	0.02	–	0.2	–	15	–	680–1590	–	–	B	3	203	14	6	0.04	0.3	0.13	19	5	2

* To convert to kJ (kilojoule) multiply the values given by 4.1855
** Vitamin A activity due to vitamin A + carotenes, 1 IU vitamin A = 0.0006 mg β-carotene
*** FA = folic acid, E = α-tocopherol unless otherwise stated
† In canned juice 12

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Poly-unsaturated g	Carbohydrates: Total g	Carbohydrates: Fibre g	Calories* kcal	Vitamins: A** IU	B1 mg	B2 mg	B6 mg	Nicotinic acid mg	Pantothenic acid mg	C mg	Other vitamins*** mg
Raisins (*Vitis vinifera*) dried	18.0	2.5	0.2	–	77.4	0.9	289	20	0.11	0.08	0.3	0.5	0.09	1	biotin 0.005; FA 0.01
Raspberries (*Rubus idaeus*)	84.2	1.2	0.5	–	13.6	3.0	57	150	0.03	0.09	0.09	0.9	0.2	25	biotin 0.0019; FA 0.005
frozen, sweetened	74.3	0.7	0.2	–	24.6	2.2	98	70	0.02	0.02	–	0.6	–	21	–
Raspberry juice, fresh	88	0.2	0	–	11	trace	40	120	0.02	–	–	–	–	20	–
Strawberries (*Fragaria* sp.)	89.9	0.7	0.5	–	8.4	1.3	37	60	0.03	0.07	0.04	0.6	0.26	60	biotin 0.0011; FA 0.005
frozen, sweetened	75.7	0.4	0.2	–	23.5	0.6	92	30	0.02	0.06	–	0.5	–	53	–
Tangerines (*Citrus nobilis*)	87	0.8	0.2	–	11.6	0.5	46	420	0.07	0.02	0.07	0.2	–	31	–
per lb as purchased (refuse 26%)	*292*	*2.7*	*0.7*	–	*39*	*1.7*	*154*	*1410*	*0.23*	*0.07*	*0.23*	*0.7*	–	*104*	–
Whortleberries (*Vaccinium myrtillus*)	83.2	0.7	0.5	–	15.3	1.5	62	100	0.03	0.06	0.091	0.5	0.12	14	FA 0.008
frozen, sweetened	72.3	0.6	0.3	–	26.5	0.9	105	30	0.04	0.05	–	0.4	–	8	–
Vegetables															
Artichokes (*Cynara scolymus*)	85.5	2.7	0.2	–	10.6	2.4	49	160	0.08	0.05	–	1.0	0.4	9	–
Asparagus (*Asparagus officinalis*)	92.9	2.1	0.2	–	4.1	0.8	21	900	0.18	0.20	0.14	1.5	0.62	33	E 2.5; FA 0.11
per lb as purchased (refuse 44%)	*236*	*5.3*	*0.5*	–	*10.4*	*2.0*	*53*	*2290*	*0.46*	*0.51*	*0.36*	*3.8*	*1.57*	*84*	*E 6.4; FA 0.28*
canned, drained solids	92.5	2.4	0.4	–	3.4	0.8	21	800	0.06	0.10	0.03	0.8	0.15	15	biotin 0.002; FA 0.03
Beans															
kidney (*Phaseolus vulgaris*)	11.6	21.3	1.6	–	61.6	4.0	338	0	0.6	0.22	0.28	2.1	0.98	2	E 4
lima (*Phaseolus lunatus*)	67.5	8.4	0.5	–	22.1	1.8	123	290	0.24	0.12	0.55	1.4	1.3	29	biotin 0.01; FA 0.13
canned, drained solids	74.7	5.4	0.3	–	18.3	1.8	96	190	0.03	0.05	0.08	0.5	0.11	6	FA 0.013
string (*Phaseolus vulgaris*)	90.1	1.9	0.2	–	7.1	1.0	32	600	0.07	0.11	0.14	0.5	0.2	19	E<0.1; K 0.29; FA 0.028
per lb as purchased (refuse 12%)	*360*	*7.6*	*0.8*	–	*28.3*	*4.0*	*128*	*2400*	*0.28*	*0.44*	*0.56*	*2.0*	*0.8*	*76*	*E<0.4; K 1.2; FA 0.12*
canned, drained solids	91.9	1.4	0.1	–	5.2	1.0	24	470	0.03	0.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Content per 100 grammes edible portion (unless otherwise stated)	Other organic constituents: Malic acid mg	Citric acid mg	Oxalic acid mg	Excess acid A / Excess base B	Elements: Na Sodium mg	K Potassium mg	Ca Calcium mg	Mg Magnesium mg	Mn Manganese mg	Fe Iron mg	Cu Copper mg	P Phosphorus mg	S Sulphur mg	Cl Chlorine mg
Raisins (*Vitis vinifera*) dried	–	–	–	B	31	725	62	42	0.32	3.5	0.2	101	42	9
Raspberries (*Rubus idaeus*)	40	1300	15	B	3	190	49	23	0.51	1.0	0.13	22	18	22
frozen, sweetened	–	–	–	B	1	100	13	11	–	0.6	–	17	–	–
Raspberry juice, fresh	–	–	–	B	7	141	29	18	–	1.0	–	14	7	10
Strawberries (*Fragaria* sp.)	160	1080	19	B	1	145	21	12	0.06	1.0	0.13	21	12	11
frozen, sweetened	–	–	–	B	1	104	13	–	–	0.6	–	16	–	–
Tangerines (*Citrus nobilis*)	–	–	–	B	2	110	40	11	0.04	0.4	0.1	18	10	2
per lb as purchased (refuse 26%)	–	–	–	*B*	*7*	*369*	*134*	*37*	*0.13*	*1.3*	*0.3*	*60*	*34*	*7*
Whortleberries (*Vaccinium myrtillus*)	100	1560	15	B	1	89	15	10	2.3	1.0	0.11	13	11	8
frozen, sweetened	–	–	–	B	1	66	6	4	–	0.4	–	11	–	–
Vegetables														
Artichokes (*Cynara scolymus*)	170	100	–	B	43	430	51	–	0.36	1.3	0.2	94	20	22
Asparagus (*Asparagus officinalis*)	100	110	5.2	B	2	240	22	20	0.19	1.0	0.14	62	46	53
per lb as purchased (refuse 44%)	*254*	*279*	*13.2*	*B*	*5*	*610*	*56*	*51*	*0.48*	*2.5*	*0.36*	*157*	*117*	*135*
canned, drained solids	–	–	–	B	236[1]	166	19	–	–	1.9	–	53	–	–
Beans														
kidney (*Phaseolus vulgaris*)	–	–	–	B	2	1310	106	132	2.0	6.1	–	429	–	25
lima (*Phaseolus lunatus*)	170	650	4.3	B	1	680	52	66	–	2.8	0.86	142	60	9
canned, drained solids	–	–	–	B	236[2]	210	28	–	–	2.4	–	70	–	–
string (*Phaseolus vulgaris*)	130	30	30	B	1.7	256	56	26	0.45	0.8	0.07	44	30	33
per lb as purchased (refuse 12%)	*519*	*120*	*120*	*B*	*7*	*1020*	*223*	*104*	*1.8*	*3.2*	*0.28*	*176*	*120*	*132*
canned, drained solids														

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Poly unsaturated g	Carbohydrates: Total g	Carbohydrates: Fibre g	Calories* kcal	Vitamins: A** IU	B_1 mg	B_2 mg	B_6 mg	Nicotinic acid mg	Pantothenic acid mg	C mg	Other vitamins*** mg
Beets (beetroots) (*Beta vulgaris*) peeled	87.3	1.6	0.1	–	9.9	0.8	43	20	0.03	0.04	0.05	0.4	0.12	10	FA 0.02
tops	90.9	2.2	0.3	–	4.6	1.3	24	6100	0.05	0.17	–	0.3	0.26	30	biotin 0.003, FA 0.06
Broadbeans mature, dry (*Vicia faba*)	12.6	24.0	2.2	–	58.2	5.9	339	30	0.53	0.30	–	2.5	–	6	–
Broccoli (*Brassica oleracea var botrytis*)	89.1	3.6	0.3	–	5.9	1.5	32	2500	0.1	0.23	0.17	0.9	1.3	113	FA 0.05
frozen	90.7	3.3	0.2	–	5.1	1.1	28	1900	0.07	0.13	–	0.6	–	78	–
Brussels sprouts (*Brassica oleracea var gemmifera*)	84.8	4.7	0.4	–	8.7	1.2	47	550	0.1	0.16	0.16	0.9	0.72	100	E 1, K 0.8–3, biotin 0.0004, FA 0.05
per lb as purchased (refuse 8%)	*354*	*19.6*	*1.7*	–	*36.3*	*5.0*	*196*	*2300*	*0.4*	*0.67*	*0.67*	*3.8*	*3.0*	*417*	*E 4, K 3.3–13, biotin 0.0016, FA 0.21*
Cabbage red (*Brassica oleracea var capitata rubra*)	91.8	1.5	0.2	–	5.9	1.1	26	50	0.07	0.05	0.15	0.4	0.32	50	E 0.2, biotin 0.002
white (var *capitata alba*)	92.1	1.4	0.2	–	5.7	1.5	25	70	0.05	0.04	0.11	0.32	0.26	46	E 0.7, FA 0.08
Carrots (*Daucus carota*)	88.6	1.1	0.2	–	9.1	1.0	40	11000[1]	0.06	0.06	0.12	0.6	0.27	2–10	E 0.45, biotin 0.003, FA 0.008
per lb as purchased (refuse 18%)	*330*	*4.1*	*0.7*	–	*33.8*	*3.7*	*149*	*41000*	*0.22*	*0.22*	*0.45*	*2.2*	*1.0*	*7–37*	*E 1.67, biotin 0.011, FA 0.03*
canned, drained solids	91.2	0.8	0.3	–	6.7	0.8	30	15000	0.03	0.02	0.04	0.3	0.11	3	biotin 0.002, FA 0.003
Cauliflower (*Brassica oleracea var botrytis*)	91.0	2.7	0.2	–	5.2	1.0	27	60	0.11	0.10	0.2	0.6	1.0	78	E 0.15, K 3.6, biotin 0.017, FA 0.022
Celery (*Apium graveolens*) leaves and stalks	94.1	0.9	0.1	–	3.9	0.6	17	240	0.05	0.03	–	0.4	–	9	E 0.7
root	88.4	1.8	0.3	–	8.5	1.3	40	16	0.03	0.03	–	0.7	–	8	E 0.2
Chard, Swiss (*Beta vulgaris var cicla*)	90.8	1.6	0.4	–	5.6	1.0	27	6500	0.03	0.09	–	0.4	0.17	34	E 1.5, FA 0.03
Chicory (*Cichorium intybus*)	96.2	0.8	0.1	–	3.7	0.6	16	–	0.07	0.12	–	0.40	–	10	–

Content per 100 grammes edible portion (unless otherwise stated)	Other organic constituents: Malic acid mg	Citric acid mg	Oxalic acid mg	Excess acid A / Excess base B	Elements: Sodium Na mg	Potassium K mg	Calcium Ca mg	Magnesium Mg mg	Manganese Mn mg	Iron Fe mg	Copper Cu mg	Phosphorus P mg	Sulphur S mg	Chlorine Cl mg
Beets (beetroots) (*Beta vulgaris*) peeled	0	110	338	B	84	303	25	23	0.94	0.7	0.19	33	15	61
tops	–	–	916	B	130	570	119	71	1.3	3.3	0.09	40	35	40
Broadbeans mature, dry (*Vicia faba*)	–	–	–	B	–	–	77	–	–	6.3	–	374	–	–
Broccoli (*Brassica oleracea var botrytis*)	120	210	–	B	15	400	103	24	0.15	1.1	1.4	78	137	76
frozen	–	–	–	B	13	244	43	21	–	0.7	–	60	–	–
Brussels sprouts (*Brassica oleracea var gemmifera*)	200	240	–	B	12	450	29	20	0.27	1.5	0.1	80	78	40
per lb as purchased (refuse 8%)	*835*	*1000*	–	*B*	*50*	*1880*	*121*	*83*	*1.13*	*6.3*	*0.4*	*334*	*326*	*167*
Cabbage red (*Brassica oleracea var capitata rubra*)	–	–	–	B	4	266	35	18	0.1	0.5	0.06	30	–	100
white (var *capitata alba*)	–	–	–	B	13	227	46	23	0.1	0.5	0.06	27.5	–	37
Carrots (*Daucus carota*)	24	90	33	B	50	311	37	21	0.06–0.25	0.7	0.08	36	21	40
per lb as purchased (refuse 18%)	*89*	*335*	*123*	*B*	*186*	*1160*	*138*	*78*	*0.22–0.93*	*2.6*	*0.30*	*134*	*78*	*149*
canned, drained solids	–	–	–	B	236[2]	110	26	5	–	0.7	0.04	22	–	445
Cauliflower (*Brassica oleracea var botrytis*)	390	210	0	B	16	400	25	7	0.17	1.1	0.14	56	29	30
Celery (*Apium graveolens*) leaves and stalks	170	10	50	B	96	291	39	25	0.16	0.5	0.01	40	22	137
root	–	–	34	B	100	300	60	12	0.16	0.9	0.15	60	–	50
Chard, Swiss (*Beta vulgaris var cicla*)	–	–	690	B	147	550	110	65	0.3	2.7	0.11	29	–	–
Chicory (*Cichorium intybus*)	–	–	–	B	10	182	18	13	0.30	0.69	0.14	21	18	25

* To convert to kJ (kilojoule) multiply the values given by 4.1855

** Vitamin A activity due to vitamin A + carotenes, 1 IU vitamin A = 0.0006 mg β-carotene.

*** FA = folic acid, E = α tocopherol unless otherwise stated.

[1] Vitamin A content in dark varieties; in light varieties 2000

[2] Unsalted 39

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Poly-unsaturated g	Carbohydrates: Total g	Carbohydrates: Fibre g	Calories* kcal	Vitamins: A** IU	Vitamins: B_1 mg	Vitamins: B_2 mg	Vitamins: B_6 mg	Vitamins: Nicotinic acid mg	Vitamins: Pantothenic acid mg	Vitamins: C mg	Vitamins: Other vitamins*** mg	Other organic constituents: Malic acid mg	Other organic constituents: Citric acid mg	Other organic constituents: Oxalic acid mg	Excess acid A / Excess base B	Elements: Sodium Na mg	Elements: Potassium K mg	Elements: Calcium Ca mg	Elements: Magnesium Mg mg	Elements: Manganese Mn mg	Elements: Iron Fe mg	Elements: Copper Cu mg	Elements: Phosphorus P mg	Elements: Sulphur S mg	Elements: Chlorine Cl mg
Chives (*Allium schoenoprasum*)	91.3	1.8	0.3	–	5.8	1.1	28	5800	0.04	0.11	–	0.3	–	22	–	–	–	1.1	B	3	250	76	32	–	0.9	0.11	26	–	–
Corn (sweet). See Maize																													
Cress, garden (*Lepidium sativum* ssp. *sativum*)	89.4	2.6	0.7	–	5.5	1.1	32	9300	0.08	0.26	–	1.0	–	69	–	–	–	–	B	14	606	81	–	–	1.3	–	76	–	–
Cucumbers (*Cucumis sativus*)	95.6	0.8	0.1	–	3.0	0.6	13	300	0.04	0.05	0.04	0.2	0.3	8	biotin 0.001; FA 0.001	240	10	25	B	5	140	25	9	0.15	1.1	0.06	27	12	30
per lb as purchased (refuse 5%)	*412*	*3.4*	*0.4*	–	*13*	*2.6*	*56*	*1290*	*0.17*	*0.22*	*0.17*	*0.9*	*1.3*	*34*	*biotin 0.004; FA 0.004*	*1030*	*43*	*108*	*B*	*22*	*603*	*108*	*39*	*0.65*	*4.7*	*0.26*	*116*	*52*	*129*
Dandelion greens (*Taraxacum officinale*)	85.6	2.7	0.7	–	9.2	1.6	45	14000	0.19	0.26	–	–	–	36	–	–	–	25	B	76	430	187	–	0.3	3.1	0.15	66	17	99
Eggplants (*Solanum melongena*)	92.4	1.2	0.2	–	5.6	0.9	25	10	0.05	0.05	–	0.6	0.23	5	–	170	0	6.9	B	0.9	190	17	10	0.11	0.4	0.08	26	9	24
Endives (*Cichorium endivia*)	93.1	1.7	0.1	–	4.1	0.9	20	3300	0.10	0.20	–	0.72	–	10	–	–	–	27.3	B	18	400	104	13	0.22	1.7	0.09	38	26	71
Fennel (*Foeniculum vulgare*)	90	1.5	0.1	–	6.4	0.5	27	3500	0.23	0.11	0.10	0.2	0.25	31	FA 0.1; biotin 0.003	–	–	–	B	331	784	100	–	–	2.7	–	51	–	–
Garlic (*Allium sativum*) bulbs	63.8	5.3	0.2	–	29.3	1.1	129	trace	0.21	0.08	–	0.6	–	9	–	–	–	–	B	32	515	38	36	–	1.4	–	134	–	–
Horse-radishes (*Armoracia lapathifolia*)	76.6	2.8	0.3	–	18.1	2.8	80	30	0.06	0.11	0.18	0.6	–	120	–	–	–	–	B	9	554	105	33	–	2.0	0.14	70	212	18
Kale (*Brassica oleracea* var. *acephala*)	87.5	4.2	0.8	–	6.0	1.3	38	8900	0.16	0.26	0.19	2.0	0.1–1.4	115	E 8; biotin 0.0005; FA 0.05	50	350	13	B	75	410	179	37	0.5	2.2	0.09	73	115	122
Kohlrabi (*Brassica oleracea* var. *gongylodes*), tubers	90.3	2.0	0.1	–	6.6	1.0	29	20	0.06	0.04	0.12	0.3	0.1	53	FA 0.01	–	–	–	B	10	392	41	48	0.11	0.5	0.14	51	–	57
Leeks, leaves (*Allium porrum*)	87.8	2.0	0.3	–	9.4	1.2	44	50	0.06	0.04	–	0.5	–	18	E 1.0	–	–	–	B	5	300	60	18	0.07	1.0	0.3	50	72	40
Lentils, dried (*Lens esculenta*)	11.1	24.7	1.1	–	60.1	3.9	340	60	0.50	0.25	0.49	2.0	1.5	–	biotin 0.013; FA 0.1	–	–	–	B	36	810	79	77	–	8.6	0.7	377	122	64
Lettuce (*Lactuca sativa*), headed	95.1	1.3	0.2	–	2.5	0.5	14	970	0.06	0.07	0.07	0.3	0.1	8	E 0.6; biotin 0.003; FA 0.02	170	20	7.1	B	12	140	35	10	0.80	2.0	0.07	26	12	39–74
Maize (*Zea mays*)	72.7	3.5	1.0	–	22.1	0.7	96	400[1]	0.15	0.12	0.22	1.7	0.89	12	biotin 0.006; FA 0.03	0	0	5.2	B	0.4	300	3	38	0.15	0.7	0.06	111	32	14
canned, drained solids	75.9	2.6	0.8	–	19.8	0.8	84	350[1]	0.03	0.05	0.27	0.9	0.28	4	biotin 0.003; FA 0.008	–	–	–	B	2362	97	5	19	–	0.5	–	49	–	–
Mushrooms (champignons) (*Psalliota campestris*)	90.8	2.8[3]	0.24	–	3.7	0.9	22	0	0.1	0.44	0.05	6.2	2.1	5	E 0.83[4]; biotin 0.016; FA 0.03; D 150 IU	–	–	–	B	5	520	9	13	0.08	0.8	1.8	116	34	25

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Protein g	Fats: Total g	Fats: Poly unsaturated g	Carbohydrates: Total g	Carbohydrates: Fibre g	Calories* kcal	Vitamins: A** IU	B1 mg	B2 mg	B6 mg	Nicotinic acid mg	Pantothenic acid mg	C mg	Other vitamins*** mg	Constituents: Malic acid mg	Citric acid mg	Oxalic acid mg	Excess acid A / Excess base B	Sodium Na mg	Potassium K mg	Calcium Ca mg	Magnesium Mg mg	Manganese Mn mg	Iron Fe mg	Copper Cu mg	Phosphorus P mg	Sulphur S mg	Chlorine Cl mg
Onions (*Allium cepa*) ripe	89.1	1.5	0.1	–	8.7	0.6	38	40	0.03	0.04	0.1	0.2	0.17	10	E 0.26, biotin 0.004, FA 0.01	170	20	23	A	10	130	27	8	0.36	0.5	0.13	36	51	24
dried	4	8.7	1.3	–	82.1	4.4	350	200	0.25	0.18	–	1.4	–	35	–	–	–	–	A	88	1383	158	–	–	3.1	–	256	–	–
Parsley (*Petroselinum crispum*)	85.1	3.6	0.6	–	8.5	1.5	44	8500	0.12	0.26	0.2	1.2	0.03	172	biotin 0.0004, FA 0.04	–	–	190	B	28	880	203	52	0.94	6.2	0.21	63	190	156
Parsnips (*Pastinaca sativa*)	79.1	1.7	0.5	–	17.5	2.0	76	30	0.08	0.09	0.1	0.2	0.5	16	biotin 0.0001, FA 0.02	350	130	10	B	17	342	50	22	0.03–0.34	0.7	0.10	77	26	30
Peas (*Pisum sativum*) green, unripe	75.0	6.3	0.4	–	17.0	2.0	84	640	0.32	0.15	0.18	2.5	0.82	27	E 0.6, K 0.3, biotin 0.009, FA 0.025	80	110	1.3	B	2	370	26	30	0.41	2.0	0.23	116	50	33
green, frozen	80.7	5.4	0.3	–	12.8	1.9	73	680	0.32	0.10	–	2.0	–	19	–	–	–	–	B	129	150	20	24	–	2.0	–	90	–	–
canned	82.3	3.4	0.4	–	12.7	1.3	67	450	0.11	0.06	0.05	0.9	0.17	9	E 0.02, biotin 0.002, FA 0.01	–	–	0.8	B	260†	201	25	25	–	1.8	0.21	67	44	318
dried, split	9.3	24.2	1.0	–	62.7	1.2	348	120	0.87	0.29	0.05	3.0	2.1	–	biotin 0.02, FA 0.03	–	–	–	B	42	880	73	116	2.0	6.0	0.8	303	129	60
edible, podded	86.2	2.6	0.1	–	10.5	1.5	53	55	0.06	0.10	–	0.8	–	30	–	–	–	–	B	–	–	44	–	–	1.4	–	54	–	–
Peppers (*Capsicum* spp.) green chillies	92.8	1.2	0.2	–	5.3	1.4	24	420	0.08	0.08	–	0.4	–	128	–	–	–	16	B	4.2	186	9	12	0.13	0.4	0.11	25	19	13
Potato chips	1.8	5.3	39.8	–	50.0	1.6	568	trace	0.21	0.07	–	4.8	–	16	–	–	–	–	B	340	880	40	48	–	1.8	0.36	139	–	–
Potatoes (*Solanum tuberosum*) raw	79.8	2.1	0.1	–	17.7	0.5	76	trace	0.11	0.04	0.2	1.2	0.3	20	E 0.06, K 0.08, biotin 0.0001, FA 0.006	0	510	5.7	B	3	410	14	27	0.17	0.8	0.16	53	29	35
per lb as purchased (refuse 19%)	*293*	*7.7*	*0.4*	–	*65*	*1.8*	*279*	*trace*	*0.40*	*0.15*	*0.7*	*4.4*	*1.1*	*73*	*E 0.22, K 0.29, biotin 0.0004, FA 0.022*	*0*	*1874*	*21*	*B*	*11*	*1510*	*51*	*99*	*0.62*	*2.9*	*0.59*	*195*	*107*	*129*
dried	7.1	8.3	0.6	–	80.4	1.4	352	trace	0.25	0.10	–	4.8	–	26	–	–	–	–	B	84	1600	44	–	–	2.4	–	203	–	–
Pumpkins (*Cucurbita* spp.)	95.0	0.8	0.1	–	3.5	0.6	15	1600	0.05	0.11	–	0.6	–	9	–	150	0	–	B	1	457	21	12	0.04	0.8	0.08	44	10	37
Purslane (*Portulaca oleracea* var *sativa*)	92.5	1.7	0.4	–	3.8	0.9	21	2500	0.03	0.10	–	0.5	–	25	–	–	–	–	B	2	754	103	151	–	3.5	–	39	–	–
Radishes (*Raphanus sativus*)	93.7	1.1	0.1	–	3.6	0.7	18	10	0.04	0.04	0.1	0.3	0.18	26	FA 0.01	–	–	–	B	15	260	30	15	0.05	1.0	0.13	31	37	37
Rhubarb (*Rheum undulatum*)	94.9	0.5	0.1	–	3.8	0.7	16	100	0.01	0.03	0.03	0.1	0.08	9	E 0.2, FA 0.003	1770	410	230–500	B	3.5	286	96	14	0.15	0.8	0.05	18	8	53

* To convert to kJ (kilojoule) multiply the values given by 4.1855
** Vitamin A activity due to vitamin A + carotenes, 1 IU vitamin A = 0.0006 mg β-carotene
*** FA = folic acid, E = α-tocopherol unless otherwise stated
† Unsalted 3

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Poly-unsaturated g	Carbo-hydrates: Total g	Carbo-hydrates: Fibre g	Calories* kcal	Vitamins: A** IU	Vitamins: B_1 mg	Vitamins: B_2 mg	Vitamins: B_6 mg	Vitamins: Nicotinic acid mg	Vitamins: Pantothenic acid mg	Vitamins: C mg	Vitamins: Other vitamins*** mg	Other organic constituents: Malic acid mg	Other organic constituents: Citric acid mg	Other organic constituents: Oxalic acid mg	Excess acid A / Excess base B	Elements: Sodium Na mg	Elements: Potassium K mg	Elements: Calcium Ca mg	Elements: Magnesium Mg mg	Elements: Manganese Mn mg	Elements: Iron Fe mg	Elements: Copper Cu mg	Elements: Phosphorus P mg	Elements: Sulphur S mg	Elements: Chlorine Cl mg
Rutabagas (*Brassica napus* var. *napobrassica*)	87.0	1.1	0.1	–	11.0	1.1	46	580	0.07	0.07	–	1.1	–	43	–	–	–	–	B	5	239	66	15	0.04	0.4	0.08	39	–	–
Salsify (*Scorzonera hispanica*)	79	3.2	0.6	–	16.4	1.8	77	10	0.04	0.04	–	0.2	–	12	–	–	–	–	B	5	320	40	–	–	1.5	–	76	–	–
Sauerkraut	92.8	1.0	0.2	–	4.0	0.7	18	50	0.03	0.04	–	0.2	0.08	14	–	–[1]	–[1]	–[1]	B	650	140	36	–	–	0.5	0.1	18	–	–
Soybeans (*Glycine hispida*), dried	10.0	34.1	17.7	10.7	33.5	4.9	403	80	1.14	0.31	0.64	2.1	1.68	trace	E 6–11; biotin 0.06; FA 0.22	–	–	–	B	4	1900	226	235	–	8.4	0.11	554	–	–
Spinach (*Spinacia oleracea*)	90.7	3.2	0.3	–	4.3	0.6	26	8100	0.10	0.20	0.20	0.6	0.3	51	E 2.5; K 0.04–3; biotin 0.007; FA 0.075	90	80	460	B	62	662	106	62	0.82	3.1	0.20	51	27	65
per lb as purchased (refuse 8%)	*379*	*13.4*	*1.3*	–	*17.9*	*2.5*	*109*	*33800*	*0.42*	*0.83*	*0.83*	*2.5*	*1.3*	*213*	*E 10.4; K 0.17–12.5; biotin 0.029; FA 0.031*	*376*	*334*	*1920*	*B*	*259*	*2760*	*442*	*259*	*3.42*	*12.9*	*0.83*	*213*	*113*	*271*
canned	93.0	2.0	0.4	–	3.0	0.7	19	5500	0.02	0.06	0.095	0.3	0.06	14	biotin 0.002; FA 0.05	–	–	364	B	320[2]	260	85	–	–	2.1	–	26	–	–
frozen	91.3	3.0	0.3	–	4.2	0.8	25	8100	0.1	0.16	–	0.5	–	35	–	–	–	–	B	53	385	105	–	–	2.5	–	45	–	–
Squash, summer (zucchini) (*Cucurbita pepo* var. *medullosa*)	94.6	1.2	0.1	–	3.6	0.6	17	320[3]	0.05	0.09	–	1.0	–	19	–	–	–	–	B	1	202	28	–	0.14	0.4	–	29	–	–
Sweet potatoes (*Ipomoea batatas*)	70.6	1.7	0.4	–	26.3	0.7	114	8800	0.10	0.06	0.32	0.6	0.93	21	E 4.0; biotin 0.004; FA 0.012	0	70	56	B	5	530	32	31	0.15–0.52	0.7	0.15	47	15	85
canned	70.7	1.0	0.2	–	27.5	0.6	114	5000	0.03	0.03	–	0.6	–	8	–	–	–	–	B	48	120	13	–	–	0.7	–	29	–	–
Tomatoes (*Lycopersicon esculentum*)	93.5	1.1	0.2	–	4.7	0.5	22	900	0.06	0.04	0.1	0.6	0.31	23	E 0.27; biotin 0.004; FA 0.008	150	390	7.5	B	3	268	13	11	0.19	0.6	0.10	27	11	51
canned	93.7	1.0	0.2	–	4.3	0.4	21	900	0.06	0.03	0.07	0.7	0.2	17	biotin 0.0018; FA 0.003	–	–	–	B	130[4]	217	6	–	0.04	0.5	0.09	19	–	–
Tomato juice, canned	93.6	0.9	0.1	–	4.3	0.2	19	800	0.05	0.03	0.19	0.7	0.30	16	FA 0.007	23	336	–	B	230[4]	230	7	7	–	0.9	–	18	–	–
Tomato ketchup	68.6	2.0	0.4	–	25.4	0.5	106	1400	0.09	0.07	–	1.6	–	15	–	–	–	–	B	1042	363	22	21	–	0.8	–	50	–	–
Tomato puree	86.0	2.3	0.5	–	9.5	0.5	44	1200	0.09	0.06	0.18	1.5	–	9	–	–	–	–	B	590	1160	60	–	–	1.0	–	34	–	–
Turnips (*Brassica rapa*)	91.5	1.0	0.2	–	6.6	0.9	30	trace	0.04	0.07	0.11	0.6	0.02	36	E 0.02; biotin 0.0001; FA 0.004	230	0	0	B	37	230	39	7	0.04	0.5	0.07	30	22	41
greens	90.3	3.0	0.3	–	5.0	0.8	28	7600	0.21	0.39	0.98	0.8	0.38	139	E 2.3; FA 0.04	–	–	15	B	10	440	260	19	1.4	1.8	0.09	58	54	168
Watercress (*Nasturtium officinale*)	93.3	2.2	0.3	–	3.0	0.7	19	4000	0.1	0.27	–	0.9	0.1	75	–	–	–	–	B	*60*	301	151	17	0.54	2.0	0.04	*46*	147	109

* To convert to kJ (kilojoule) multiply the values given by 4.1855.
** Vitamin A activity due to vitamin A + carotenes; 1 IU vitamin A = 0.0006 mg β-carotene
*** FA = folic acid; E = α-tocopherol unless otherwise stated.
[2] Unsalted 34

Content per 100 grammes edible portion (unless otherwise stated)	Water	Proteins	Fats		Carbohydrates		Calories*	Vitamins								Other organic constituents			Excess acid A / Excess base B	Elements									
	Water g	Proteins g	Total g	Poly unsaturated g	Total g	Fibre g	kcal	A** IU	B_1 mg	B_2 mg	B_6 mg	Nicotinic acid mg	Pantothenic acid mg	C mg	Other vitamins*** mg	Malic acid mg	Citric acid mg	Oxalic acid mg		Sodium Na mg	Potassium K mg	Calcium Ca mg	Magnesium Mg mg	Manganese Mn mg	Iron Fe mg	Copper Cu mg	Phosphorus P mg	Sulphur S mg	Chlorine Cl mg
Yeast (*Saccharomyces cerevisiae*) baker's, compressed	71.0	12.1	0.4	–	11.0	–	86	trace	0.71	1.65	1.2	11.2	5.3	trace	biotin 0.4, FA 0.5	–	–	–	A	16	610	13	59	–	4.9	–	394	–	–
brewer's, dried	5.0	38.8	1.0	–	38.4	1.7	283	trace	15.6	4.28	4.2	37.9	9.5	trace	biotin 0.08, FA 2.4	–	–	–	A	121	1700	210	231	0.53	17.3	3.32	1753	–	–
Yeast, torula (*Torulopsis utilis*)	6.0	38.6	1.0	–	37.0	3.3	277	trace	15.0	5.0	3.5	50.0	10.0	–	biotin 0.1, FA 3.0	–	–	–	A	15	2046	424	165	–	20	–	1713	–	–
Nuts																													
Almonds (*Amygdalus communis*) dried	4.7	18.6	54.2	10.8	19.5	2.6	598	75	0.25	0.92	0.10	3.5	0.58	trace	E 15, biotin 0.02, FA 0.045	–	–	–	B	3	690	234	252	1.9	4.7	0.14	504	150	2
Brazil nuts (*Bertholletia excelsa*)	4.6	14.3	66.9	18.4	10.9	3.1	654	10	1.0	0.07	0.11	7.7	0.23	2	E 6.5, FA 0.005	–	–	–	A	2	670	127	225	2.8	2.8	1.1	600	198	61
Cashew nuts (*Anacardium occidentale*)	5.2	17.2	45.7	3	29.3	1.4	561	100	0.43	0.25	–	1.8	–	–	–	–	–	–	–	15	464	38	267	–	3.8	–	373	–	–
Chestnuts (*Castanea sativa*)	48	3.4	1.9	–	45.6	1.3	213	0	0.23	0.22	0.29	0.5	0.3	6	E 0.5, biotin 0.0013	–	–	–	B	2	410	46	42	3.7	1.4	0.06	74	29	11
dried	9.0	6.7	4.1	–	78.8	2.5	378	0	0.34	0.39	–	0.8	–	0	–	–	–	–	B	4	875	57	–	–	3.3	–	170	–	–
Coconuts (*Cocos nucifera*)	48	4.2	34	0.6	12.8	3.3	351	0	0.06	0.03	0.06	0.6	0.33	2	E 1, FA 0.028	–	–	–	B	17	363	13	39	1.31	1.7	0.32	95	44	114
dried	3.5	7.2	64.9	0.6	23.0	3.9	662	0	0.06	0.04	–	0.6	–	0	–	–	–	–	B	29	588	26	90	–	3.3	0.55	187	76	196
Coconut water	94.2	0.3	0.2	–	4.7	trace	22	0	trace	trace	–	0.1	–	2	–	–	–	–	–	25	147	20	28	–	0.3	–	13	–	–
Hazelnuts (*Corylus avellana*)	6.0	12.7	60.9	23	18	3.5	627	100	0.47	0.55	0.54	1.6	1.15	7.5	E 21, FA 0.067	–	–	–	B	3	618	250	150	4.2	4.5	1.35	320	198	10
Peanuts (*Arachis hypogaea*) roasted	1.8	26.2	48.7	14.0	20.6	2.7	582	360	0.32	0.13	0.3	17.1	2.14	0	biotin 0.034, FA 0.057, E 6.5	–	–	–	A	3	740	74	181	1.51	2.2	0.27	407	377	7
Pecans (*Carya illinoinensis*)	3.4	9.2	71.2	14	14.6	2.3	687	130	0.86	0.13	0.19	0.9	–	2	E 1.5	–	–	–	–	trace	603	73	142	3.5	2.4	–	289	–	–
Pine nuts (*Pinus pinea*)	3.1	13.0	60.5	–	20.5	1.1	635	30	1.28	0.23	–	4.5	–	–	–	–	–	–	–	–	–	12	–	–	5.2	–	604	–	–
Pistachio nuts (*Pistacia vera*)	5.3	19.3	53.7	10	19.0	1.9	594	230	0.67	–	–	1.4	–	–	–	–	–	–	–	–	972	131	158	–	7.3	–	500	–	–
Walnuts (*Juglans regia*)	3.5	14.8	64.0	47.5	15.8	2.1	651	30	0.3	0.13	1.0	1.0	0.7	2	biotin 0.037, FA 0.077, E 1.5	–	–	–	A	4	450	99	134	1.8	3.1	0.31	380	146	23
Cereals, Cereal products																													
Barley (*Hordeum* spp.), pearled	12.0	9.0	1.4	0.8	76.5	0.8	346	0	0.12	0.05	–	3.1	0.5	0	–	–	70	–	A	3	160	16	37	1.68	2.0	0.4	189	116	105
Bread																													
white, enriched, 4% nonfat milk solids	35.6	8.7	3.2	–	50.8	0.2	270	trace	0.25	0.21	–	2.4	–	trace	–	–	–	–	A	507	105	84	22	0.31	2.5	0.2	97	–	–
toasted	25.1	10.1	3.7	–	58.8	0.2	314	trace	0.23	0.24	–	2.8	–	trace	–	–	–	–	A	590	122	98	28	–	2.9	–	113	–	1040
wholemeal	36.4	9.1	2.6	–	49.3	1.5	241	trace	0.30	0.10	–	2.8	–	trace	–	–	–	–	A	530	256	84	78	–	2.3	–	254	–	–
French, unenriched	30.6	9.1	3.0	–	55.4	0.2	290	trace	0.08	0.08	–	0.8	–	trace	–	–	–	–	A	580	90	43	22	–	0.7	–	85	–	–

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Content per 100 grammes edible portion (unless otherwise stated)	Water	Proteins	Fats		Carbohydrates		Calories*	Vitamins								Other organic constituents			Excess acid A / Excess base B	Elements									
			Total	Poly-unsaturated	Total	Fibre		A**	B_1	B_2	B_6	Nicotinic acid	Pantothenic acid	C	Other vitamins***	Malic acid	Citric acid	Oxalic acid		Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	Manganese Mn	Iron Fe	Copper Cu	Phosphorus P	Sulphur S	Chlorine Cl
	g	g	g	g	g	g	kcal	IU	mg	mg	mg	mg	mg	mg	mg	mg	mg	mg		mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
Bread (continued)																													
pumpernickel	34.0	9.1	1.2	–	53.1	1.1	246	–	0.23	0.14	–	1.2	–	–	–	–	–	–	A	569	454	84	71	–	2.4	–	229	–	–
rye, American	35.5	9.1	1.1	–	52.1	0.4	243	0	0.18	0.07	–	1.4	–	0	–	–	–	–	A	557	145	75	42	1.3	1.6	0.28	147	–	1025
zwieback	5.0	10.7	8.8	–	74.3	0.3	423	40	0.05	0.07	–	1.3	–	–	–	–	–	–	A	250	150	13	–	–	0.6	–	69	–	–
Cornflakes	3.8	7.9	0.4	–	85.3	0.7	385	0	0.43[1]	0.1	–	2.1	0.19	0	FA 0.006	–	–	5.6	A	660	160	10	17	0.05	1.4	0.17	45	93	–
Cornstarch	12.0	0.3	trace	–	87.9	0.1	362	0	trace	0.08	0.005	0.03	–	–	–	–	–	–	A	4	4	trace	2	–	0.5	–	30	–	6
Flour																													
buckwheat	14.1	11.7	2.7	–	70	2.6	327	0	0.58	0.15	–	2.9	1.5	–	–	–	–	–	A	1	680	33	–	2.09	2.2	0.7	263	–	–
farina, unenriched	10.3	11.4	0.9	–	77.0	0.4	371	0	0.06	0.10	–	0.7	–	–	–	–	–	–	A	2	83	25	25	–	1.5	–	107	–	–
maize (corn)	12.0	7.8	2.6	–	76.8	0.7	368	340[2]	0.20	0.06	0.06	1.4	0.55	0	biotin 0.006; FA 0.01; E 0.3	–	–	–	A	1	120	6	–	–	1.8	–	164	–	–
rye, light	11	9.4	1.0	–	77.9	0.4	357	0	0.15	0.07	–	0.6	–	–	–	–	–	–	A	1	156	22	73	–	1.1	–	185	–	–
rye, medium	11	11.4	1.7	–	74.8	1.0	325	0	0.30	0.12	–	2.9	–	–	–	–	–	–	A	1	203	27	83	–	2.6	–	262	–	–
soybean, full fat	8.0	36.7	20.3	–	30.2	2.4	347	110	0.85	0.31	0.66	2.1	1.68	0	biotin 0.07; FA 0.43	–	–	–	B	–	1660	199	235	–	8.4	–	558	–	–
medium fat	8.0	43.4	6.7	–	36.6	2.5	264	80	0.83	0.36	–	2.6	–	0	–	–	–	–	B	–	2025	244	286	–	9.1	–	634	–	–
wheat, whole	12	13.3	2.0	–	71.0	2.3	333	0	0.55	0.12	–	4.3	–	0	–	–	–	–	A	3	370	41	113	–	3.3	0.2	372	–	–
white, unenriched	12	10.5	1.0	–	76.1	0.3	363	0	0.06	0.05	–	0.9	–	0	–	–	–	–	A	2	95	16	25	–	0.8	–	87	–	–
white, enriched	12	10.5	1.0	–	76.1	0.3	364	0	0.44	0.26	–	3.5	–	0	–	–	–	–	A	2	95	16	25	–	2.9	–	87	–	–
white, self-raising, enriched	11.5	9.3	1.0	–	74.2	0.4	352	0	0.44	0.26	–	3.5	–	0	–	–	–	–	A	1079	90	265	–	–	2.9	–	466	–	–
Muffins (enriched flour)	38.0	7.8	10.1	–	42.3	0.1	294	100	0.17	0.23	–	1.4	–	trace	–	–	–	–	A	441	125	104	–	–	1.6	–	151	–	–
Noodles, unenriched, dry	10.1	13.0	2.9	–	73	0.4	376	100	0.2	0.08	–	2.1	–	–	–	–	–	–	A	7	157	20	–	–	2.1	–	196	–	–
Oatflakes	10.3	13.8	6.6	2.7	67.6	1.4	387	–	0.55	0.14	0.75	1.1	0.92	0	E 0.25	–	–	–	A	2	340	53	145	4.9	3.6	0.74	407	199	49
Pancakes (enriched flour)	50.1	7.1	7.0	–	34.1	0.1	231	120	0.17	0.22	–	1.3	–	trace	–	–	–	–	A	425	123	101	–	–	1.3	–	139	–	–
Piecrust, plain, unenriched, unbaked	20.9	5.7	31.0	–	40.7	0.1	464	0	0.03	0.03	–	0.5	–	0	–	–	–	–	–	568	46	13	–	–	0.4	–	47	–	–
Popcorn, popped	4.0	12.7	5.0	2.0	76.7	2.2	386	–	0.39	0.12	–	2.2	–	0	–	–	–	–	A	3	240	11	–	–	2.7	0.31	281	–	–
Pretzels	4.5	9.8	4.5	–	75.9	0.3	390	0	0.02	0.03	–	0.7	–	0	–	–	–	–	A	1680	130	22	–	–	1.5	–	131	–	–
Rice																													
whole	12.0	7.5	1.9	–	77.4	0.9	360	0	0.29	0.05	–	4.7	–	0	E 1.2	–	–	–	A	9	150	32	119	1.7	1.6	0.36	221	121	–
polished	12.0	6.7	0.4	–	80.4	0.3	362	0	0.07	0.03	0.15	1.6	0.63	–	E 0.35	–	–	–	A	6	113	24	28	1.08	0.8	0.06–0.19	94	79	27
polished, cooked	72.6	2.0	0.1	–	24.2	0.1	109	0	0.02	0.01	–	0.4	–	0	–	–	–	–	A	2[3]	38	10	8	–	0.2	–	28	27	9[3]
Semolina																													
maize	11.0	8.8	1.1	–	78.0	–	365	440[2]	0.15	0.05	0.05	0.5	–	–	–	–	–	–	A	1	80	4	20	–	1.0	–	73	–	–
wheat	13.1	10.3	0.8	–	76	–	362	0	0.12	0.04	0.085	1.3	–	–	E 1.8[4]	–	–	–	A	1	112	17	–	–	1	–	87	–	–
Spaghetti, unenriched, dry	10.4	12.5	1.2	–	75.2	0.3	369	0	0.09	0.06	–	2.0	–	–	–	–	–	–	A	5	–	22	–	–	1.5	–	165	–	–
Tapioca, dry	12.6	0.6	0.2	–	86.4	0.1	360	0	0	0.1	–	0	–	0	–	–	–	–	0	4	20	12	2	0.69	1.0	0.07	12	4	16
Wheat germ	11.5	26.6	10.9	2.9	46.7	2.5	363	650	2.0	0.68	0.92	4.2	2.2	0	FA 0.31; E 15[4]	–	340	–	A	2	780	72	336	–	9.4	1.3	1118	–	70

* To convert to kJ (kilojoule) multiply the values given by 4.1855.
** Vitamin A activity due to vitamin A + carotenes; 1 IU vitamin A = 0.0006 mg β-carotene.
*** FA = folic acid; E = α-tocopherol unless otherwise stated.

[1] Enriched.
[2] Based on yellow maize.
[3] Unsalted.
[4] Total tocopherol.

Content per 100 grammes edible portion (unless otherwise stated)	Water	Protein	Fats: Total	Fats: Poly-unsaturated	Carbohydrates: Total	Carbohydrates: Fibre	Calories*	Vitamins: A**	B₁	B₂	B₆	Nicotinic acid	Pantothenic acid	C	Other vitamins***	constituents: Malic acid	Citric acid	Oxalic acid	Excess acid A / Excess base B	Na Sodium	K Potassium	Ca Calcium	Mg Magnesium	Mn Manganese	Fe Iron	Cu Copper	P Phosphorus	S Sulphur	Cl Chlorine
	g	g	g	g	g	g	kcal	IU	mg	mg	mg	mg	mg	mg	mg	mg	mg	mg		mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
nfectionery, Sugar																													
amel[1]	7.6	4.0	10.2	–	76.6	0.2	399	10	0.03	0.17	–	0.2	–	trace	–	–	–	–	B	226	192	148	–	–	1.4	–	122	–	–
ocolate																													
ilk, sweetened	0.9	7.7	32.3	–	56.9	0.4	520	270	0.06	0.34	–	0.3	–	0	E 1.1	–	–	–	A	86	420	228	58	–	1.1	1.1	251	67	151
lain, sweetened	0.9	4.4	35.1	1.2	57.9	0.5	528	10	0.02	0.14	–	0.3	–	trace	–	–	–	–	A	19	397	63	107	–	1.4	1.1	142	32	–
coa, dry powder	5.6	19.8	24.5	0.4	43.6	5.7	299	10	0.09	0.11	–	1.9	–	0	E 3.1[2]	–	–	450	A-B	60	900–3200	114	420	3.53	12.5	3.4	709	203	51
xtrose, anhydrous	trace	0	0	–	99.5	0	385	0	0	0	–	0	–	0	–	–	–	–	0	1	0.4	–	–	–	–	–	–	–	–
ney	17.2	0.3	0	–	82.3	–	304	0	trace	0.04	0.01	0.3	0.06	1	FA 0.003	–	–	–	0	7	51	5	3	0.03	0.5	0.2	6	–	29
ns	29	0.6	0.1	–	70.0	1.0	272	10	0.01	0.03	–	0.2	–	2	–	–	–	–	B	16	112	12	10	–	1.0	0.23	9	6.5	9
ple syrup	33	–	–	–	65	–	252	–	–	–	–	–	–	0	–	–	–	–	B	10	176	104	–	–	1.2	–	8	–	–
lasses	24.0	–	–	–	60.0	–	232	–	0–0.08	0–0.16	0.27	2.8	0.5	0	biotin 0.009, FA 0.01	–	–	–	B	40	1500	273	–	0.04	6.7	1.9	69	–	317
gar																													
rown	2.1	0	0	–	96.4	–	373	0	0.01	0.03	–	0.2	–	0	–	–	–	–	B	24	230	85	–	–	3.4	–	19	–	–
ane or beet, white	trace	0	0	–	99.5	0	385	0	0	0	–	0	–	0	–	–	–	–	0	0.3	0.5	0	–	–	0.04	–	0	–	–
verages, nonalcoholic																													
bonated soft drinks[3]	88	–	–	–	12	0	46	–	–	–	–	–	–	–	–	–	–	–	0	1–15	1	–	–	–	–	–	–	–	–
a drinks	90	–	–	–	10	–	39	–	–	–	–	–	–	–	–	–	–	–	B	–	–	–	–	–	–	–	–	–	–
fee[4] (unsweetened)	98.5	0.3	0.1	–	0.8	–	5	0	0.01	0.01	–	0.9	–	0	–	18	29	1	B	1–6	80	5	9	0.09	0.2	–	5	–	0.6
[5] (unsweetened)	99	0.1	0	–	0.4	–	2	0	0	0.04	–	0.1	–	1	–	–	–	10	0	0–2	16	0.3–5	1–13	0.69	0.2	–	1–4	–	0.4
verages, alcoholic			Alcohol[6]																										
r	90.6	0.5	3.6		4.8[7]	0	47	0	0.004	0.03	0.05	0.88	0.08	–	biotin 0.0005	–	–	–	B	5	38	4	–	–	–	–	–	–	–
ndy	–	–	35–40		–	–	245–280	–	–	–	–	–	–	–	–	–	–	–	0	3	4	–	–	–	–	–	–	–	–
it wine	–	–	5.2		1.0	–	40	–	–	–	–	–	–	–	–	–	–	–	B	7	72	–	–	–	–	–	–	–	–
t wine	–	0.2	15.0		14.0	–	161	–	–	–	–	–	–	–	–	–	–	–	B	4	75	5	10	–	0.3	0.09	11	–	8
n	–	–	35.1		–	–	246	–	–	–	–	–	–	–	–	–	–	–	0	2	3	–	–	–	–	–	–	–	–
sky	–	–	35		–	–	245	–	–	–	–	–	–	–	–	–	–	–	0	0.3	1	–	–	–	–	–	–	–	–
e[8]	–	0	8.8–12.5		0.2–8.0	–	60–120	–	0.001 to 0.005	0.01	0.09	0.05	0.04	–	FA 0.001	0–280	6–58	–	B	4–7	20–120	7	7–16	0.3	0.3–5	0.05–0.25	10	15	2

* To convert to kJ (kilojoule) multiply the values given by 4.1855 ** Vitamin A activity due to vitamin A + carotenes, 1 IU vitamin A = 0.0006 mg β-carotene *** FA = folic acid, E = α-tocopherol unless otherwise d [1] Full-cream products. [2] Total tocopherol [3] Not true mineral waters [4] Caffeine 75–100 mg, trigonelline 100 mg, acetic acid 20 mg, formic acid 12 mg, chlorogenic acid and other phenolic acids 200 mg [5] Caffeine 40–60 mg [6] Alcohol has a calorific value of 7 kcal/g [7] Extract [8] Tartaric acid 163–234 mg, lactic acid 71–248 mg, succinic acid 90–130 mg, aromatic acids 56–136 mg, glycerol 0.8–2.6 g

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Poly-unsaturated g	Fats: Cholesterol g	Carbohydrates g	Calories* kcal	Vitamins: A** IU	Vitamins: B_1 mg	Vitamins: B_2 mg	Vitamins: B_6 mg	Vitamins: Nicotinic acid mg	Vitamins: Pantothenic acid mg	Vitamins: C mg	Other vitamins*** mg
Fats, Oils															
Butter	17.4	0.6	81.0	4	0.28	0.7	716	3300	trace	0.01	trace	0.1	trace	trace	E 2.4; D 40 IU
Cod-liver oil	0	0	99.9	–	0.85	0	901	85000	–	0	–	0	–	–	E 26[2]; D 8500 IU
Corn oil	trace	0	99.9	56	0	0	883	–	–	–	–	–	–	–	E ~ 19
Cottonseed oil	trace	0	99.9	50	0	0	883	–	–	–	–	–	–	–	E ~ 30
Lard	1.0	trace	99.0	10	0.1	0	901	0	0	0	–	0	–	0	E 2
Margarine, salted	15.5	0.6	81.0	14	–	0.4	720	3300	–	–	–	–	–	0	–
Mayonnaise	15.1	1.1	78.9	32[3]	–	3.0	718	280	0.02	0.04	–	trace	–	0	–
Mustard, brown	78.1	5.9	6.3	–	–	5.3	91	–	–	–	–	–	–	–	–
Olive oil	trace	0	99.9	8	0	0	883	0	0	0	–	0	–	0	E ~ 3
Palm oil	trace	0	99.9	9	0	0	883	–	–	–	–	–	–	–	E 30
Peanut butter	1.8	27.8	49.4	11.9	0	17.2	581	–	0.13	0.13	0.30	15.7	2.5	0	biotin 0.04; FA 0.06
Peanut oil	trace	0	99.9	29	0	0	883	–	–	–	–	–	–	–	E 13
Safflower oil	trace	0	99.9	72	0	0	883	–	–	–	–	–	–	–	E 31
Soybean oil	trace	0	99.9	60	0	0	883	–	–	–	–	–	–	–	E 18
Sunflower oil	trace	0	99.9	63	0	0	883	–	–	–	–	–	–	–	E 22
Vegetable fat	0	0	100	7	–	0	884	–	0	0	0	0	0	0	–
Dairy products, Eggs															
Butter. See under 'Fats', above															
Cheese															
Camembert	51.3	18.7	22.8	–	–	1.8	287	1010	0.05	0.45	0.25	1.45	0.1–0.9	0	biotin 0.005
Cheddar	37	25.0	32.2	1	0.10	2.1	398	1310	0.03	0.46	0.07	0.1	0.40	10.0	biotin 0.004; FA 0.016
cottage, creamed	78.3	13.6	4.2	trace	0.015	2.9	106	170	0.03	0.25	–	0.1	–	0	–
cottage, uncreamed	79.0	17.0	0.3	–	–	2.7	86	10	0.03	0.82	0.01	0.1	–	1	biotin 0.002; FA 0.03
cream	51	8.0	37.7	1	0.12	2.1	374	1540	0.02	0.24	–	0.1	–	0	–
Parmesan	30.0	36.0	26.0	–	–	2.9	393	1060	0.02	0.73	–	0.2	–	0	–
Roquefort	40.0	21.0	32.0	–	–	1.8	378	800	0.06	0.3–0.7	–	0.4–0.9	0.5–0.7	0	biotin 0.003
Swiss (Emmentaler)	34.9	27.4	30.5	–	–	3.4	398	1140	0.05	0.33	0.09	0.1	–	0.5	E 0.35[2]; D 100 IU
Cream															
heavy 30%	64.1	2.2	30.4	0.8	–	2.9	288	1100[5]	0.025	0.17	0.035	0.07	–	1	D 40 IU
Eggs															
whole, raw	74.0	12.8	11.5	2.3	0.46	0.7	162	1180	0.12	0.34	0.25	0.1	1.6	0	D 200 IU; B_{12} 0.002; E 1; K 0.002; biotin 0.02; FA 0.005

Content per 100 grammes edible portion (unless otherwise stated)	Purine nitrogen mg	Excess acid A / Excess base B	Sodium Na mg	Potassium K mg	Calcium Ca mg	Magnesium Mg mg	Manganese Mn mg	Iron Fe mg	Copper Cu mg	Phosphorus P mg	Sulphur S mg	Chlorine Cl mg
Fats, Oils												
Butter	–	A	10[1]	23	16	1	0.04	0.2	0.03	16	9	–
Cod-liver oil	–	0	0.1	–	–	–	–	–	–	–	–	–
Corn oil	–	0	–	–	–	–	–	–	–	–	–	–
Cottonseed oil	–	0	–	–	–	–	–	–	–	–	–	–
Lard	–	A	0.3	0.2	1	–	–	0.1	0.02	3	25	4
Margarine, salted	–	–	987	23	20	–	–	0	–	16	–	–
Mayonnaise	–	A	702	53	18	2	–	0.5	–	28	–	–
Mustard, brown	–	A	1307	130	124	48	–	1.8	–	134	–	–
Olive oil	–	0	0.1	trace	0.5	–	–	0.08	0.07	–	–	–
Palm oil	–	0	–	–	–	–	–	–	–	–	–	–
Peanut butter	–	A	607[4]	670	63	178	–	2.0	–	407	225	–
Peanut oil	–	0	–	–	–	–	–	–	–	–	–	–
Safflower oil	–	0	–	–	–	–	–	–	–	–	–	–
Soybean oil	–	0	–	–	–	–	–	–	–	–	–	–
Sunflower oil	–	0	–	–	–	–	–	–	–	–	–	–
Vegetable fat	0	0	0	0	0	0	0	0	0	0	0	0
Dairy products, Eggs												
Butter. See under 'Fats', above												
Cheese												
Camembert	–	A	1150[4]	109	382	18	–	0.5	0.08	184	–	–
Cheddar	–	A	700	82	750	43	–	1.0	–	478	–	–
cottage, creamed	–	A	229	85	94	–	–	0.3	–	152	–	–
cottage, uncreamed	–	A	290	72	90	–	–	0.4	–	175	–	–
cream	–	A	250	74	62	–	–	0.2	–	95	–	–
Parmesan	–	A	755[4]	153	1140	50	–	0.4	0.36	781	251	1110[4]
Roquefort	–	A	–	–	700	–	–	1	–	–	–	–
Swiss (Emmentaler)	–	A	620[4]	100	1180	55	–	0.9	0.13	860	–	1210[4]
Cream												
heavy 30%	–	B	38	78	75	–	–	0–0.1	–	63	–	–
Eggs												
whole, raw	–	A	135	138	54	13	0.05	2.3	0.03	205	197	159

* To convert to kJ (kilojoule) multiply the values given by 4.1855.
** Vitamin A activity due to vitamin A + carotenes; 1 IU vitamin A = 0.0006 mg β-carotene.
*** FA = folic acid; E = α-tocopherol unless otherwise stated.
[1] Unsalted.
[2] Total tocopherol.
[3] Prepared with corn oil.
[4] Variable, depends on salt content.
[5] In summer; in winter 500.

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Poly unsaturated g	Fats: Cholesterol g	Carbohydrates g	Calories* kcal	Vitamins: A** IU	Vitamins: B_1 mg	Vitamins: B_2 mg	Vitamins: B_6 mg	Vitamins: Nicotinic acid mg	Vitamins: Pantothenic acid mg	Vitamins: C mg	Other vitamins*** mg	Purine nitrogen mg	Excess acid A / Excess base B	Sodium Na mg	Potassium K mg	Calcium Ca mg	Magnesium Mg mg	Manganese Mn mg	Iron Fe mg	Copper Cu mg	Phosphorus P mg	Sulphur S mg	Chlorine Cl mg
Egg white, raw	87.6	10.9	0.2	–	0	0.8	51	0	0.02	0.23	0.22	0.1	0.14	0	biotin 0.007, FA 0.001	–	A	192	148	9	11	0.04	0.2	0.03	17	208	161
Egg yolk, raw	50.0	16.1	31.9	6.7	1.6	0.6	360	1400	0.32	0.52	0.30	0.02	4.2	0	B_{12} 0.002, E 3, D 350 IU, biotin 0.05, FA 0.013	–	A	50	123	141	16	0.09	7.2	0.02	569	194	142
1 egg, medium (48 grammes)	*35.5*	*6.1*	*5.5*	*1.1*	*0.22*	*0.4*	*77*	*580*	*0.06*	*0.16*	*0.12*	*0.04*	*0.8*	*0*	–[3]	–	*A*	*66*	*67*	*26*	*6*	*0.02*	*1.3*	*0.02*	*98*	*95*	*69*
1 egg white, medium (31 grammes)	*27.0*	*3.3*	*0.1*	*–*	*0*	*0.3*	*16*	*0*	*0.01*	*0.07*	*0.07*	*0.03*	*0.04*	*0*	–[3]	–	*A*	*57*	*46*	*3*	*3*	*0.01*	*0.06*	*0.01*	*5*	*64*	*48*
1 egg yolk, medium (17 grammes)	*8.5*	*2.8*	*5.4*	*1.1*	*0.22*	*0.1*	*61*	*580*	*0.05*	*0.09*	*0.05*	*trace*	*0.7*	*0*	–[3]	–	*A*	*9*	*21*	*23*	*3*	*0.01*	*1.2*	*0.01*	*93*	*32*	*21*
Egg powder	4.1	47.0	41.2	–	2.14	4.1	592	4460	0.35	1.23	0.08	0.2	7.4	0	D 240 IU	–	A	519	483	190	41	–	8.7	0.18	800	630	592
Milk (cow's)[1, 2] pasteurized, whole	88.5	3.2	3.7	0.1	0.01	4.6	64	140	0.04	0.15	0.05	0.07	0.33	1	E 0.06[4], B_{12} 0.0006, biotin 0.002, D 0.5–4 IU, FA 0.0001	–	B	75	139	133	13	0.002	0.04	0.01	88	29	105
buttermilk, cultured	91.2	3.5	0.5	–	–	4.0	35	35	0.04	0.18	0.04	0.1	0.36	1	B_{12} 0.0003, E 0.05[4], biotin 0.002, FA 0.0003	–	B	57	147	109	16	–	0.1	0.02	95	30	100
condensed (sweetened)	27.1	8.1	8.7	0.2	–	54.3	321	350	0.1	0.38	0.06	0.2	0.85	1	biotin 0.003, D 3.5 IU	–	B	140	340	262	25	–	0.1	–	206	–	–
canned, evaporated (unsweetened)	73.8	7.0	7.9	0.2	–	9.7	138	350	0.06	0.36	0.03	0.2	0.85	1	biotin 0.003, FA 0.0007, D 3.5 IU	–	B	100	270	252	25	–	0.2	–	205	–	–
dried, whole	2.0	26.4	27.5	0.7	–	38.2	502	1200	0.28	1.2	0.3	0.7	2.7	10	B_{12} 0.002, biotin 0.013	–	B	410	1330	909	112	–	0.6	0.16	708	234	784
nonfat	3.0	35.9	1.0	–	–	52.0	362	30	0.35	1.80	0.4	0.9	3.5	10	B_{12} 0.002, biotin 0.016, FA 0.0024	–	B	525	1335	1300	111	–	0.6	–	1016	300	1130
skimmed	90.9	3.5	0.07	–	0.003	4.8	34	7	0.038	0.17	0.05	0.1	0.28	2	E 0.03[4], biotin 0.002	–	B	53	150	123	14	–	0.1	0.003	97	–	100
Breast milk[1, 2]	87.7	1.03	4.4	0.3	0.01–0.02	6.9	70	330	0.01	0.04	0.02	0.18	0.24	5	E 0.23[4], B_{12} trace, biotin 0.001, FA 0.0001, D 0.4–9.7 IU	–	B	17	50	33	3	trace	0.05	0.05	14	14	36
Camel's milk[1]	87.1	3.7	4.2	–	–	4.1	69	120	–	–	–	–	–	6	–	–	B	–	–	–	–	–	–	–	–	–	–
Goat's milk[1]	86.6	3.6	4.2	–	–	4.8	71	120	0.05	0.12	0.027	0.2	0.35	2	B_{12} 0.0001, biotin 0.002, FA 0.0002, D 2 IU	–	B	34	180	129	13	0.008	0.1	0.04	103	16	150
Mare's milk[1]	91.1	2.1	1.25	–	–	6.3	44	45	0.03	0.02	0.03	0.05	0.30	10	B_{12} 0.0003, FA 0.0001	–	B	–	70	100	10	–	–	–	60	–	20
Sheep's milk[1]	81.6	5.6	7.5	–	–	4.4	107	200	0.07	0.50	–	0.50	0.35	3	B_{12} 0.0003, biotin 0.009, FA 0.0002	–	B	30	190	190	–	–	0.1	–	150	–	140
Whey	93.3	0.9	0.3	–	–	4.7	25	8–16	0.04	0.08	0.02	0.07	0.35	1.5	biotin 0.002, E 0.024[4]	–	B	45	129	50	1	–	–	–	53	–	–
Yoghurt[5]	86.1	4.8	3.8	–	–	4.5	71	145	0.045	0.024	0.05	0.18	–	2	–	–	B	62	190	150	–	–	0.2	–	135	–	–
Meat, Poultry (raw unless otherwise stated)																											
Bacon medium fat	20.0	9.1	65.0	6.5	0.22	trace	625	0	0.36	0.11	0.35	1.8	–	0	E 0.4	28	A	1770	225	13	15	–	1.2	–	108	–	–

[1] Values per 100 g	pH	Spec grav	Casein	Albumin	Total protein	Nonprotein N	Ash
Breast milk	6.97	1.031	0.40 g	0.30 g	1.0–6.0 g	32.4 mg	0.21 g
Camel's milk	–	1.031	2.90 g	0.90 g	3.4–3.7 g	–	0.68 g
Cow's milk	6.60	1.031	2.80 g	0.40 g	2.0–6.0 g	13–14 mg	0.72 g
Goat's milk	–	1.031	2.87 g	0.89 g	3.6–3.8 g	40 mg	0.85 g
Mare's milk	7.20	1.034	1.40 g	–	2.13 g	–	0.36 g
Sheep's milk	6.54	1.036	4.17 g	0.98 g	4.5–5 g	42.5 mg	0.93 g

* To convert to kJ (kilojoule) multiply the values given by 4.1855

** Vitamin A activity due to vitamin A + carotenes, 1 IU vitamin A = 0.0006 mg β-carotene

*** FA = folic acid, E = α tocopherol unless otherwise stated.

[2] See also pages 687–689

[3] Can be calculated from the 100 g values.

[4] Total tocopherol.

[5] Citric acid 232 mg, lactic acid 487 mg, acetic acid 44 mg

Content per 100 grammes edible portion (unless otherwise stated)	Water g	Proteins g	Fats: Total g	Fats: Poly-unsaturated g	Fats: Cholesterol g	Carbohydrates g	Calories* kcal	Vitamins: A** IU	Vitamins: B_1 mg	Vitamins: B_2 mg	Vitamins: B_6 mg	Vitamins: Nicotinic acid mg	Vitamins: Pantothenic acid mg	Vitamins: C mg	Vitamins: Other vitamins*** mg	Purine nitrogen mg	Excess acid A / Excess base B	Elements: Sodium Na mg	Elements: Potassium K mg	Elements: Calcium Ca mg	Elements: Magnesium Mg mg	Elements: Manganese Mn mg	Elements: Iron Fe mg	Elements: Copper Cu mg	Elements: Phosphorus P mg	Elements: Sulphur S mg	Elements: Chlorine Cl mg
Beef																											
loin, lean	69.7	21.1	8.2	–	–	0	164	20	0.09	0.19	–	5.1	–	–	–	–	A	65	355	12	24	–	3.2	–	196	–	–
rib, lean	66.8	20.7	11.6	–	–	0	193	20	0.09	0.18	–	5.0	–	–	–	–	A	65	355	12	24	–	3.1	–	208	–	–
round, total edible	69.0	19.5	12.5	0.3	0.12	–	196	–	0.08	0.17	0.50	4.7	0.52	–	biotin 0.003; FA 0.01; B_{12} 0.002	50	A	68	400	11	22	–	2.9	0.08	180	–	–
rump, total edible	56.5	17.4	25.3	–	–	0	303	50	0.08	0.16	–	4.2	–	–	–	–	A	–	–	10	21	–	2.6	–	160	–	–
sirloin, lean	71.8	21.5	5.7	–	–	0	143	10	0.09	0.19	–	5.2	–	–	–	–	A	65	355	12	24	–	3.2	–	200	–	–
canned, corned	59.3	25.3	12.0	–	–	0	216	0	0.02	0.2	–	3.4	–	0	–	36	A	1300	60	20	–	–	4.3	–	106	–	–
dried, salted	47.7	34.3	6.3	–	0.23	0	203	0	0.11	0.32	–	3.7	–	0	–	–	A	4300	200	20	–	–	5.1	–	404	–	–
hamburger, cooked	54.2	24.2	20.3	–	–	0	364	40	0.09	0.21	–	5.4	–	–	–	–	A	47	450	11	21	–	3.2	–	194	–	–
brain	79.4	10.4	8.0	–	2.36	0.8	120	580	0.15	0.23	0.16	4.0	1.8	14	biotin 0.007; B_{12} 0.005; FA 0.012	–	A	104	191	11	12	–	1.6	0.2	265	–	–
heart	75.5	16.8	6.0	0.2	0.15	0.6	128	20	0.53	0.88	0.29	6.8	2.0	6	biotin 0.007; B_{12} 0.01; FA 0.003	94	A	85	286	5	17	–	4.0	0.3	195	–	–
kidneys	75.9	15.4	6.7	–	0.41	0.9	130	1000	0.25	2.1	0.39	6.4	4	11	B_{12} 0.04; FA 0.06; biotin 0.009	94	A	245	231	11	11	0.08	5.5	0.35	219	161	256
liver	69.9	19.7	3.8	0.7	0.32	5.9	136	20000	0.30	2.9	0.7	13.6	7.3	31	E 1; B_{12} 0.065; biotin 0.10; FA 0.29	110	A	116	292	7	15	0.27	6.5	2.1	352	–	–
lungs	80.1	16.9	2.0	–	0.35	trace	90	–	0.09	0.32	–	4.0	1.4	0	B_{12} 0.003; biotin 0.006	–	A	–	–	12	–	–	6.6	–	196	–	–
pancreas	70.6	14.6	12.3	–	–	trace	173	17	0.10	0.40	–	4.2	3.5	58	B_{12} 0.014; FA 0.02; biotin 0.014	–	A	62	249	9	15	–	1.0	0.06	335	–	–
spleen	77	18.1	3.4	–	–	trace	108	–	0.13	0.28	0.12	4.2	1.2	6	B_{12} 0.005; biotin 0.006	–	A	99	379	7	–	–	8.9	–	236	–	–
tongue	68.0	16.4	15.0	–	–	0.4	207	0	0.14	0.27	0.13	5.0	2.0	0	biotin 0.003; B_{12} 0.003	55	A	80	260	8	10	–	3.0	0.07	182	–	13
tripe	78	19.0	2.0	–	0.15	0	99	0	0.01	0.09	–	3.0	–	0	–	22	A	46	19	69	–	–	0.9	–	132	–	–
Calf (see also 'Veal')																											
brain	79.4	10.2	8.3	–	–	0.8	122	–	0.20	0.20	0.16	3.7	2.5	18	biotin 0.06; B_{12} 0.002	–	A	172	265	9	14	–	2.6	0.14	353	–	–
heart	78.3	12.2	7.6	0.5	–	0.8	124	30	0.6	1.05	–	6.3	2.8	5	biotin 0.015; B_{12} 0.01; FA 0.01	–	A	120	230	16	18	–	2.2	0.34	350	–	–
kidneys	75.0	16.7	6.4	0.18	–	0.8	132	70	0.37	2.5	0.5	6.5	4.0	13	B_{12} 0.025; FA 0.04	–	A	200	290	10	–	–	3.4	0.51	171	–	–
liver	70.7	19.2	4.7	–	0.36	4.1	140	22500	0.28	2.72	1.2	17	9.7	32	E 0.9–1.6f; K 0.15; FA 0.05; B_{12} 0.06; biotin 0.075; D 50 IU	120	A	84	295	8	15	0.34	5.4	4.4	311	–	–
sweetbreads	75	19.6	3.0	–	0.28	0	111	–	0.08	0.17	–	2.6	–	–	–	400	A	73	519	–	–	–	0.9	0.08	–	–	–
tongue	74.3	18.5	5.3	–	–	0.9	130	–	–	–	–	–	–	–	–	–	A	84	200	9	–	–	3.0	–	190	–	–
Chicken, flesh and skin																											
fryers	72.7	20.6	5.6	1.2	0.09	–	138	170	0.1	0.2	0.50	6.8	0.80	2.5	E 0.21; biotin 0.011; FA 0.003	60	A	83	359	12	37	0.02	1.8	0.3	200	–	85
roasters	66.9	19.5	12.6	–	–	0	197	410	0.08	0.12	–	7.4	–	–	–	–	A	–	–	11	–	–	1.5	–	191	–	–
hens and cocks	61.3	19.0	18.8	–	–	0	251	610	0.06	0.13	–	9.2	–	–	–	–	A	–	–	11	–	–	1.3	–	182	–	–
liver	72.2	19.7	3.7	1.0	0.20	2.9	141	12100	0.4	2.5	0.80	10.8	4.1	35	FA 0.38; B_{12} 0.004; D 50 IU	–	A	85	179	12	13	0.18	7.9	0.32	236	–	–
Duck, medium fat	54.0	16	28.6	6.9	0.07	0	326	–	0.10	0.24	–	5.6	–	8	–	60	A	85	285	15	–	0.03	1.8	0.4	188	–	85

* To convert to kJ (kilojoule) multiply the values given by 4.1855.
** Vitamin A activity due to vitamin A + carotenes; 1 IU vitamin A = 0.0006 mg β-carotene.
*** FA = folic acid; E = α-tocopherol unless otherwise stated.
f Total tocopherol.

Content per 100 grammes edible portion (unless otherwise stated)	Water	Protein	Fats			Carbohydrates	Calories*	Vitamins								Purine nitrogen	Excess acid A / Excess base B	Elements									
			Total	Poly-unsaturated	Cholesterol			A**	B_1	B_2	B_6	Nicotinic acid	Pantothenic acid	C	Other vitamins***			Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	Manganese Mn	Iron Fe	Copper Cu	Phosphorus P	Sulphur S	Chlorine Cl
	g	g	g	g	g	g	kcal	IU	mg	mg	mg	mg	mg	mg	mg	mg		mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
Gelatin, dry	13.0	85.6	0.1	–	–	0	335	0	0	0	–	0	–	0	–	0	0	–	–	–	–	–	–	–	–	–	–
Goat	70	18.7	9.4	0.4	–	0	165	0	0.17	0.32	–	5.6	–	0	–	–	A	–	–	11	–	–	2.2	–	–	–	–
Goose, medium fat	51.0	16.4	31.5	2.5	–	0	354	–	0.10	0.24	0.6	5.6	–	–	–	100	A	85	420	15	–	0.05	1.8	0.3	188	–	–
liver	66	17	10	–	0.49	5.5	184	–	0.02	–	0.9	4	–	–	–	–	A	140	230	10	–	–	–	–	180	–	–
Ham																											
raw	53.0	15.2	31.0	–	0.07–0.1	0	345	0	0.74	0.18	0.44	4.0	0.64	0	FA 0.01, B_{12} 0.001, biotin 0.005	49	A	76	339	9	18	0.06	2.3	0.31	168	–	–
boiled	57.0	19.5	20.6	2.0	0.07	0	269	0	0.54	0.26	–	4.2	0.53	0	–	45	A	876	348	10	–	–	2.5	–	150	–	–
smoked, raw	42.0	16.9	35.0	–	0.11	0.3	389	0	0.7	0.19	0.40	4.0	–	0	–	–	A	2530	248	10	20	–	2.5	–	207	–	2060
canned, spiced	65.0	18.3	12.3	–	0.07	1.5	193	0	0.53	0.19	–	3.8	–	0	–	–	A	1150	293	11	20	–	2.7	0.09	156	–	–
Hare	73	22.3	0.9'	–	0.08	0.2	103	0	0.09	0.19	–	5.0	–	–	–	–	A	50	400	12	–	–	3.2	–	157	–	–
Horse flesh, lean	74.3	21.7	2.6	–	–	0.9	120	–	0.07	0.12	–	4.3	0.50	1	E 0.5†, B_{12} 0.003	–	A	44	332	10	–	–	2.7	–	150	–	–
Lamb (medium fat)																											
chop	52.0	14.9	32.0	0.7	0.07	0	352	–	0.13	0.18	0.33	4.3	0.59	–	E 0.6	65	A	90	345	9	14	–	2.2	–	138	–	–
leg	64.0	18.0	18.0	0.5	0.07	0	239	–	0.16	0.22	0.32	5.2	0.62	–	biotin 0.006, B_{12} 0.003, FA 0.003	81	A	78	380	10	16	–	2.7	–	213	–	–
Pork (see also 'Bacon' and 'Ham')																											
cutlets	53.9	15.2	30.6	2.8	0.07	0	341	0	0.8	0.19	0.48	4.3	0.40	0	E 0.6, B_{12} 0.001, biotin 0.005, FA 0.002	–	A	62	326	10	19	0.06	2.6	–	193	–	–
loin, lean	71.2	18.6	9.9	–	–	–	168	–	1.1	0.31	–	6.5	–	–	–	–	A	74	348	12	22	–	3.0	–	234	–	–
loin or chops, cooked	50	23.0	26.0	–	–	0	333	0	0.83	0.24	–	5.0	–	0	–	–	A	–	–	11	–	–	3.0	–	235	–	–
ribs	52.6	14.6	32.0	1.6	0.10	0	351	–	0.92	0.18	–	3.9	0.65	2	B_{12} 0.001	–	A	76	252	5	0.06	–	2.2	–	157	–	–
spare ribs, total edible	53.9	15.2	30.6	2.8	0.07	0	341	0	0.8	0.19	0.48	4.3	0.40	0	E 0.6, B_{12} 0.001, biotin 0.005, FA 0.002	–	A	62	326	9	19	0.06	2.3	–	170	–	–
canned, strained	75.7	17.1	6.0	–	–	0	127	0	0.35	0.28	–	4.7	–	0	–	–	A	–	–	14	–	–	1.7	–	180	–	–
brain	78.0	10.6	9.0	–	–	trace	126	–	0.16	0.28	–	4.3	2.8	18	B_{12} 0.003	–	A	153	312	10	11	–	3.6	0.3	300	–	–
heart	76.8	16.9	4.8	0.27	–	0.4	117	30	0.43	1.24	0.43	6.6	2.5	3	E 1.4†, B_{12} 0.003, biotin 0.02	–	A	80	257	6	15	–	3.3	0.3	132	198	113
kidneys	77.8	16.3	5.2	0.29	–	0.8	120	130	0.34	1.8	0.55	9.8	3.1	12	B_{12} 0.015, biotin 0.13	–	A	173	242	11	16	0.10	6.7	0.38	218	–	190
liver	71.6	20.6	4.8	–	–	2.6	131	10900	0.43	2.7	0.85	16.4	7.0	27	E 1.0†, B_{12} 0.010, FA 0.22, biotin 0.10	–	A	77	350	10	18	0.3	19	0.85	316	228	102
tongue	66.1	16.8	15.6	–	–	0.5	215	–	0.17	0.29	0.35	5.0	–	–	–	–	A	93	234	9	–	–	1.4	–	186	–	–
Rabbit	70.4	20.4	8.0	1.5	0.12	0	159	30	0.04	0.18	0.6	12.8	0.8	0	E 1.0†	38	A	40	385	18	–	–	2.4	–	210	199	51
Sausages																											
beef	49.2	13.8	18.4	–	–	15.7	286	–	–	–	–	–	–	–	–	–	A	1130	255	21.2	16.6	–	4.1	0.17	168	163	1770
bologna	56.2	12.1	27.5	–	–	1.1	304	–	0.16	0.22	–	2.6	–	–	–	–	A	1300	230	7	–	–	1.8	–	128	–	–
frankfurter, cervelat	55.6	12.5	27.6	–	–	1.8	256	0	0.16	0.20	–	2.7	–	0	–	–	A	1100	230	7	–	–	1.9	–	133	–	–
canned	65.7	13.0	19.6	–	–	–	232	–	0.03	0.08	–	3.1	–	–	–	–	A	711	–	10	–	–	2.7	–	185	–	1100

* To convert to kJ (kilojoule) multiply the values given by 4.1855
** Vitamin A activity due to vitamin A + carotenes, 1 IU vitamin A = 0.0006 mg β-carotene
*** FA = folic acid, E = α tocopherol unless otherwise stated.
† Total tocopherol.

Content per 100 grammes edible portion (unless otherwise stated)	Water	Proteins	Fats: Total	Fats: Poly-unsaturated	Fats: Cholesterol	Carbohydrates	Calories*	Vitamins: A**	Vitamins: B_1	Vitamins: B_2	Vitamins: B_6	Vitamins: Nicotinic acid	Vitamins: Pantothenic acid	Vitamins: C	Vitamins: Other vitamins***	Purine nitrogen	Excess acid A / Excess base B	Elements: Sodium Na	Elements: Potassium K	Elements: Calcium Ca	Elements: Magnesium Mg	Elements: Manganese Mn	Elements: Iron Fe	Elements: Copper Cu	Elements: Phosphorus P	Elements: Sulphur S	Elements: Chlorine Cl
	g	g	g	g	g	g	kcal	IU	mg	mg	mg	mg	mg	mg	mg	mg		mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
Sausages (continued)																											
mortadella	52.3	12.4	32.8	–	–	–	349	–	0.10	0.15	–	3.1	–	0	–	–	A	668	207	12	–	–	3.1	–	238	–	920
pork																											
English	50.7	8.8	28.8	–	–	9.8	335	–	–	–	–	–	–	–	–	–	A	770	158	15	11.5	–	2.5	0.12	108	73	1070
American	38.1	9.4	50.8	–	–	trace	498	0	0.43	0.17	–	2.3	–	–	–	–	A	740	140	5	–	–	1.4	–	92	–	–
salami	27.7	17.8	49.7	–	–	–	524	–	0.18	0.20	–	2.6	–	–	E 0.11	–	A	1260	302	35	–	–	–	–	–	–	2390
Sheep (see also 'Lamb' and 'Mutton')																											
kidneys	77.7	16.8	3.3	–	–	0.9	105	690	0.51	2.42	–	7.4	4.3	15	B_{12} 0.063	103	A	151	205	13	13	0.09	7.5	0.3	218	–	–
liver	70.8	21.0	3.9	–	0.12	2.9	136	50500	0.4	3.28	0.37	16.9	7.1	33	biotin 0.13; FA 0.28	–	A	51	170	13	14	0.23	10.9	6.3	349	–	–
Turkey	64.2	20.1	14.7	3.0	0.015	0.4	218	trace	0.13	0.14	–	7.9	0.75	0	FA 0.01	79	A	66	315	8	–	0.03	1.5	0.2	212	–	123
Veal																											
rib	70.0	19.5	9.0	0.6	–	0	164	–	0.14	0.26	0.43	6.5	0.50	0	biotin 0.002; FA 0.005; B_{12} 0.0007	50	A	90	301	11	16	0.03	2.9	0.25	200	–	–
round with rump	73.0	19.9	6	–	–	0	139	–	0.15	0.26	–	6.7	–	–	–	–	A	90	320	12	–	–	3.0	–	206	–	–
Venison	73.0	21.4	3.6	0.3	–	0	124	0	0.37	0.28	–	7.4	–	0	–	–	A	70	336	19	29	–	5.0	–	183	211	41
Whale meat	71	20.6	4.0	–	–	1	125	1860	0.03	0.1	–	4.4	–	8	–	–	A	78	–	12	–	–	2.4	–	144	–	–
Fish, Sea foods (raw unless otherwise stated)																											
Carp (*Cyprinus carpio*)	72.4	18.9	7.1	–	–	0	145	300	0.08	0.04	–	1.5	–	1	–	54	A	51	285	34	15	–	1	–	220	–	62
Caviar, pressed	46.0	26.9	15.0	–	0.3	3.3	262	–	0	–	–	–	–	–	–	40	A	2200	180	276	–	–	11.8	–	355	–	1800
Clams, long and round (*Mya arenaria, Ensis americana*)	83.1	10.5	1.3	–	0.12	3.1	70	–	0.1	0.19	0.08	1.5	0.6	–	biotin 0.002; FA 0.003	–	A	121	235	12	63	–	0.6	–	208	–	–
Cod (*Gadus callarias*)	81.2	17.6	0.3	–	0.05	0	78	0	0.06	0.07	0.20	2.2	0.12	2	biotin 0.0002; FA 0.001; B_{12} 0.0005	62	A	86	339	11	28	0.01	0.5	0.5	190	–	97
Crab (*Cancer pagurus*), canned or cooked, meat only	77.2	17.4	2.5	–	0.15	1.1	101	–	0.08	0.08	0.35	2.5	0.5	trace	biotin 0.005; B_{12} 0.0005; FA 0.0003	61	A	1000	110	45	48	–	0.8	1.3	182	–	–
Eel (*Anguilla anguilla*)	60.7	12.7	25.6	–	0.05	0	285	2000	0.15	0.31	0.28	2.2	–	1.8	D 5000 IU	–	A	78	247	18	18	0.03	0.7	0.03	166	130	35
smoked	50.3	18.6	27.8	–	–	0.8	333	2500	0.14	0.35	0.15	3.8	–	–	B_{12} 0.006; D 6400 IU	–	A	798	239	95	50	0.03	0.7	–	211	–	–
Flounder (*Platichthys flesus, Pleuronectes flesus*)	81.3	16.7	0.8	–	0.06	0	79	30	0.22	0.21	0.25	3.8	–	–	–	86	A	68	332	12	31	0.02	0.8	0.18	195	–	151
Frog legs (*Rana* spp.)	81.9	16.4	0.3	–	0.04	0	73	–	0.14	0.25	–	1.2	–	5	–	–	A	55	308	18	–	–	1.5	–	147	163	40
Haddock (*Melanogrammus aeglefinus*)	80.5	18.3	0.1	–	0.06	0	79	60	0.06	0.17	0.2	3.0	0.14	0	E 0.6; biotin 0.0003; B_{12} 0.001; FA 0.001	67	A	99	301	18	24	0.02	0.7	0.23	197	238	241
smoked	72.6	23.2	0.4	–	–	0	103	–	0.06	0.05	–	2.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Halibut (*Hippoglossus hippoglossus*)	75.2	18.6	5.2	–	0.06	0	126	440	0.09	0.18	0.42	6	0.30	0	biotin 0.002; B_{12} 0.001; FA 0.002	68	A	56	340	13	–	0.01	0.7	0.23	211	–	–

* To convert to kJ (kilojoule) multiply the values given by 4.1855

Content per 100 grammes edible portion (unless otherwise stated)	Water	Proteins	Fats: Total	Fats: Poly-unsaturated	Fats: Cholesterol	Carbohydrates	Calories*	Vitamins: A**	B_1	B_2	B_6	Nicotinic acid	Pantothenic acid	C	Other vitamins***	Purine nitrogen	Excess acid A / Excess base B
	g	g	g	g	g	g	kcal	IU	mg	mg	mg	mg	mg	mg	mg	mg	
Herring (*Clupea harengus*)	62.8	17.3	18.8	–	–	0	243	130	0.06	0.24	0.45	4.3	1.0	0.5	E 2[1,2], B_{12} 0.01, D 900 IU[1]	119	A
pickled	60.2	18.3	14	–	–	–	204	150	–	0.08	0.15	3.3	–	–	–	–	A
smoked	61.0	22.2	12.9	–	–	0	211	40	0.04	0.28	0.35	3.3	–	–	B_{12} 0.01	–	A
Lobster (*Homarus vulgaris*)	78.5	16.9	1.9	–	0.20	0.5	91	–	0.15	0.13	–	1.5	1.3	5	biotin 0.005, FA 0.0005	73	A
canned	77.2	18.4	1.3	–	–	0.4	92	–	0.16	0.14	–	2.2	–	4	–	–	A
Mackerel (*Scomber scombrus*)	67.2	19.0	12.2	–	0.08	0	191	450	0.15	0.35	0.70	7.7	0.46	0	E 1.6[2], B_{12} 0.01, biotin 0.002, FA 0.001, D 50 IU	–	A
smoked	59.4	23.8	13.0	–	–	0	219	–	–	–	–	–	–	–	–	–	A
Mussels (*Mytilus edulis*)	84.1	11.7	1.9	–	0.15	2.2	76	180	0.16	0.22	–	1.6	–	–	–	199	A
Ocean perch, Atlantic (*Sebastes marinus*)	77.9	18.9	3.0	–	–	0	108	30	0.09	0.08	–	2.5	–	3	–	–	A
Octopus (*Octopus bimaculatus*)	82.2	15.3	0.8	–	0.17	0	73	–	0.02	0.06	–	1.8	–	–	–	–	A
Oysters (*Ostrea* spp.)	83.0	9.0	1.2	–	0.11–0.33	4.8	68	310	0.18	0.23	0.11	2.5	0.5	trace	biotin 0.001, FA 0.004, B_{12} 0.015, D 5 IU	29	A
Perch (*Perca fluviatilis*)	79.5	18.4	0.8	–	0.07	0	86	30	0.075	0.12	–	1.7	–	–	–	–	A
Pike (*Esox lucius*)	80.2	18.2	1.2	–	–	0	89	–	0.15	0.07	–	1.7	–	–	E 0.2	45	A
Salmon																	
Atlantic (*Salmo salar*)	65.5	19.9	13.6	5.3	0.06	0	208	220	0.17	0.17	0.98	7.5	0.8	1	biotin 0.001, D 650 IU, FA 0.002, B_{12} 0.003	47	A
canned, solids and liquid	64.2	21.7	12.2	–	–	0	203	60	0.03	0.18	0.45	6.5	0.5	trace	biotin 0.015, FA 0.0005, D 500 IU	101	A
chinook	64.2	19.1	15.6	–	–	0	222	310	0.10	0.23	–	–	–	–	–	–	A
canned, solids and liquid	64.4	19.6	14.0	–	–	0	210	230	0.03	0.14	–	7.3	–	–	–	–	A
sockeye																	
canned, solids and liquid	67.2	20.3	9.3	–	–	0	171	230	0.04	0.16	–	7.3	–	–	–	–	A
smoked	58.9	21.6	9.3	–	–	0	176	–	–	–	–	–	–	–	–	–	A
Sardines, canned in oil																	
solids and liquid	50.6	20.6	24.4	–	–	0.6	311	180	0.02	0.16	0.16	4.4	0.5	0	biotin 0.005, D 300 IU, B_{12} 0.01, FA 0.002	–	A
drained solids	61.8	24.0	11.1	3	0.07	1.2	214	290	0.03	0.20	0.28	5.4	0.6	0	biotin 0.02, D 250 IU	234	A
Scallops (*Pecten* spp.)	79.8	15.3	0.2	–	–	3.3	79	0	0.04	0.06	–	1.3	0.14	–	biotin 0.0003, FA 0.0005	117	A
Shrimps (*Crangon* spp.)	78.2	18.7	2.2	–	0.14	–	97	10	0.07	0.05	0.13	1.25	–	2	B_{12} 0.001	–	A
canned, drained solids	70.4	24.2	1.1	–	0.15	0.7	116	60	0.01	0.03	0.11	1.5	0.21	0	FA 0.002, D 105 IU	–	A
Snails (*Helix*)	82	15	0.8	–	–	2	75	–	–	–	–	–	–	–	–	–	A
Trout (*Salmo trutta*)	77.6	19.2	2.1	–	–	0	101	150	0.09	0.25	–	3.5	–	–	–	92	A
Tunny (*Thunnus thynnus*), canned, solids and liquid	52.5	23.8	20.9	–	–	0	290	90	0.05	0.06	0.25	10.8	0.2	0	biotin 0.0005, B_{12} 0.001, FA 0.003	–	A

Content per 100 grammes edible portion (unless otherwise stated)	Elements: Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	Manganese Mn	Iron Fe	Copper Cu	Phosphorus P	Sulphur S	Chlorine Cl
	mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
Herring (*Clupea harengus*)	118	317	57	26	0.02	1.1	0.3	240	202	122
pickled	1000	–	30	9	–	–	–	150	–	1600
smoked	720	285	66	–	–	1.4	–	254	–	230
Lobster (*Homarus vulgaris*)	300	260	29	22	0.04	0.6	2.2	200	170	500
canned	–	–	65	–	–	0.8	–	192	–	–
Mackerel (*Scomber scombrus*)	144	358	5	33	0.02	1.0	0.16	239	197	170
smoked	–	–	–	–	–	–	–	–	–	–
Mussels (*Mytilus edulis*)	290	315	88	23	0.25	5.8	3.2	250	367	460
Ocean perch, Atlantic (*Sebastes marinus*)	94	345	46	–	–	1.0	–	212	–	–
Octopus (*Octopus bimaculatus*)	–	–	29	–	–	0.19	0.44	173	–	–
Oysters (*Ostrea* spp.)	73	110	94	42	0.2	5.5	1.2–3.7	143	–	–
Perch (*Perca fluviatilis*)	67	238	20	–	–	1	–	198	–	–
Pike (*Esox lucius*)	70	300	20	30	0.02	0.7	0.25	210	200	100
Salmon										
Atlantic (*Salmo salar*)	48	391	29	29	0.01	0.8	0.2	266	190	64
canned, solids and liquid	540	330	67	30	–	1.3	0.05	285	–	865
chinook	45	399	–	–	–	–	–	301	–	–
canned, solids and liquid	–	366	154	27	–	0.9	–	289	–	–
sockeye										
canned, solids and liquid	522	344	259	29	–	1.2	–	344	–	–
smoked	–	–	14	–	–	–	–	245	–	–
Sardines, canned in oil										
solids and liquid	510	560	354	–	–	3.5	0.04	434	–	–
drained solids	823	590	437	–	–	2.9	0.04	499	–	–
Scallops (*Pecten* spp.)	150	420	26	–	–	1.8	–	208	342	–
Shrimps (*Crangon* spp.)	140	258	63	42	–	2.0	0.43	300	–	–
canned, drained solids	–	122	115	–	–	3.1	–	263	–	–
Snails (*Helix*)	–	–	170	250	1.6	3.5	0.4	–	140	–
Trout (*Salmo trutta*)	39	470	19	–	0.03	1.0	0.33	220	–	–
Tunny (*Thunnus thynnus*), canned, solids and liquid	361	343	7	–	–	1.2	–	294	–	–

* To convert to kJ (kilojoule) multiply the values given by 4.1855
** Vitamin A activity due to vitamin A + carotenes, 1 IU vitamin A = 0.0006 mg β-carotene
*** FA = folic acid, E = α-tocopherol unless otherwise stated.
[1] Without gonads
[2] Total tocopherol.

Amino acids of foods

The amino-acid contents of foods listed in the table below have been taken from a publication[1] of the British Medical Research Council. Other collected data on the subject are available in the publications of Block and Bolling[2], Block and Weiss[3], Orr and Watt[4], and Harvey[5]. The amounts of the essential amino acids in foods are given in the tables of Souci et al.[6] and of Church and Church[7]. The amino-acid content of the FAO/WHO Reference Protein[8] is based on the minimum requirements of the individual essential amino acids.

Many of the proteins of meat and fish have a largely similar composition, like those of cereal and milk products, and it has therefore been unnecessary to list all these foods in detail. On the other hand, the amino-acid composition of the vegetable proteins shows wide variations, but since these proteins are quantitatively unimportant in the human diet the variations are without appreciable effect in nutrition. Too little is known of the amino-acid composition of fruits to justify their inclusion in the table. The phenylalanine content of fruits lies between 1.5 and 4 g/16 g N[9].

The values in the table are for the raw foods. Cookin little effect on the proteins of foods poor in carbohydrate products the proteins in the crust have a lower utilizal known that vegetables lose nitrogenous substances du ing, but this loss has no practical significance.

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[8] *Protein Requirements*, Report of a Joint FAO/WHO Expert Grou *Org. techn. Rep. Ser.*, No. 301 (1965).
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Amino-acid contents of foods (g per 16 g nitrogen*)

	Arginine	Cystine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Tyrosine	Valine	Alanine	Aspartic acid	Glutamic acid	Glycine	Prolin…
Vegetables																	
Beans, snap	5.9	1.1	2.9	5.4	7.7	5.4	0.5	3.4	2.6	1.0	3.0	5.1	2.6	6.6	1.4	3.7	4.
haricot	5.8	1.0	3.2	6.1	8.2	7.0	1.3	6.2	4.6	1.3	–	6.6	–	–	–	–	–
Beets	1.8	–	1.4	3.2	3.4	3.4	0.5	1.4	2.4	1.0	–	3.0	–	–	–	–	–
Beets, tops	6.1	1.4	1.9	3.2	6.2	3.5	2.4	5.0	4.2	1.4	4.5	5.1	–	–	–	–	–
Broccoli	5.8	–	1.8	3.8	5.3	5.4	1.8	3.0	3.4	1.3	–	4.2	–	–	–	–	–
Brussels sprouts	6.2	–	2.2	4.2	4.3	4.3	1.0	3.4	3.4	1.0	–	4.3	–	–	–	–	–
Cabbage	7.5	1.6	1.8	2.9	4.2	3.7	1.0	2.6	2.7	0.8	2.1	3.4	–	–	–	–	–
Carrots	3.5	–	1.4	4.3	5.8	4.5	1.1	3.7	3.8	0.8	–	5.4	–	–	–	–	–
Cauliflower	4.2	–	0.2	4.3	6.2	5.4	2.1	3.4	4.2	1.3	–	5.8	–	–	–	–	–
Lentils	8.3	0.6	2.2	5.3	7.0	6.2	0.6	4.2	3.7	0.8	–	5.6	–	–	–	–	–
Peas	8.6	1.0	1.8	5.0	6.9	5.3	1.0	4.0	4.0	1.0	4.2	4.6	(3.8)	(8.6)	(3.2)	(6.1)	–
Potatoes	5.3	1.3	1.4	4.5	4.6	5.0	1.6	4.2	3.7	1.3	2.9	5.1	4.2	17.1	23.8	1.9	2.
Spinach	4.5	–	1.4	4.0	6.4	5.1	1.8	4.5	4.0	1.8	–	5.1	–	–	–	–	–
Soybeans, soyflour	7.4	1.9	2.6	5.3	7.7	6.4	1.3	5.0	4.0	1.4	3.7	5.3	5.0	1.3	19.0	4.5	5.
Nuts																	
Almonds	10.1	1.8	2.2	3.8	6.6	2.6	1.3	5.1	2.7	0.8	–	5.0	–	–	–	–	–
Brazil nuts	13.3	3.0	2.1	3.7	6.9	2.6	5.1	3.4	2.6	1.1	–	4.8	–	–	–	–	–
Coconuts	12.5	1.8	2.1	4.5	7.2	3.5	1.8	4.2	3.0	2.1	–	5.6	–	–	–	–	–
Hazelnuts	14.6	2.6	1.9	5.8	6.2	2.9	1.0	3.7	2.9	1.4	3.7	6.2	–	7.0	20.5	9.4	5.6
Peanuts	10.6	1.6	2.4	4.2	6.2	3.5	1.0	5.0	2.9	1.1	3.0	5.0	2.9	14.1	2.0	5.4	5.1
Walnuts	13.0	1.8	2.2	4.3	6.9	2.6	1.8	4.3	3.4	1.0	–	5.4	–	–	–	–	–
Cereals																	
Barley, whole grain	5.0	2.1	1.9	3.8	6.9	3.4[1]	1.4	5.0	3.7	1.4	3.5	5.0	4.5	5.9	20.5	43.2	9.3
Bread, wheat, white	3.4	2.2	2.1	3.7	7.4	1.9	1.9	5.0	2.9	–	3.2	4.2	3.0	4.2	33.0	3.4	11.5
Flour, wheat, whole	4.3	2.1	2.1	3.8	6.4	2.7	1.6	4.6	2.9	1.3	3.2	4.3	3.4	5.0	27.7	3.8	10.1
white	3.4	2.2	2.1	3.7	7.0	1.9	1.6	5.4	2.9	1.3	3.4	4.2	3.2	4.2	33.4	3.4	11.7
Maize, whole grain	5.0	2.1	2.4	4.0	12.0	3.0	2.1	5.0	4.2	0.8	3.8	5.6	9.9	12.3	15.4	3.0	8.3
Oats, whole grain	6.6	1.8	1.9	4.6	7.0	3.7	1.4	5.0	3.4	1.3	3.8	5.4	5.1	4.2	18.4	4.2	5.8
Rice, whole	8.5	1.8	2.2	4.8	8.2	4.2	2.1	4.6	3.5	1.4	5.8	6.2	–	–	–	–	–
polished	8.0	1.6	2.2	4.6	8.5	3.0	2.1	4.8	3.8	1.4	5.0	6.6	5.6	4.5	10.7	6.6	4.5
Rye, whole grain	5.0	1.8	2.1	3.8	6.1	3.7	1.6	4.6	3.4	1.3	4.2	5.0	–	–	19.7	–	–
Wheat germ	6.9	1.4	2.7	3.5	5.9	6.1	1.4	3.7	4.5	1.0	–	4.6	–	–	–	–	–
Eggs, Milk																	
Eggs, whole	6.4	2.1	2.6	5.8	9.0	6.7	3.0	5.3	5.3	1.8	4.3	7.2	–	10.7	12.3	3.8	4.3
Egg white	6.2	2.2	2.4	5.8	9.0	6.6	4.0	5.9	5.0	1.9	4.2	7.8	–	11.0	12.6	4.2	4.2
Egg yolk	7.0	1.8	2.6	5.8	8.5	6.7	2.2	4.6	5.8	1.8	4.6	6.9	–	–	12.0	3.4	4.3
Milk, cow's, and dairy products	3.7	0.8[2]	2.7	6.2	9.9	7.8	2.4	5.1	4.6	1.4	5.6	7.0	3.7	8.2	22.2	1.9	9.8
Breast milk	3.4	1.9	2.2	5.6	9.4	6.2	2.1	4.0	4.5	1.6	4.8	6.2	3.8	9.3	19.8	2.2	8.6
Meat, Fish																	
Fish	5.8[3]	11.2	2.1[4]	5.1	7.5	9.0	2.9	3.7	4.5	1.0	3.0	5.3	6.1	9.4	14.1	6.1	5.9
Gelatin	7.8	trace	6.9	1.4	2.9	4.0	0.8	2.1	1.9	–	0.3	2.2	9.8	5.9	10.1	24.2	26.7[5]
Meat and meat products	6.6	1.3	3.2	5.1	7.8	8.2	2.4	4.2	4.5	1.3	3.4	5.3	6.2	9.1	15.4	4.5	4.2
brain, liver, kidney	6.1	1.3	3.2	5.1	9.0	8.2	2.4	5.1	4.5	1.3	3.4	6.1	6.2	9.1	15.4	4.5	4.2
FAO/WHO Reference Protein	–	–	–	4.3	4.9	4.3	2.3	2.9	2.8	1.4	2.9	4.3	–	–	–	–	–

* Average nitrogen content per 100 g protein. [1] Barley, pearled 2.2. [2] Cheese 0.5. [3] Shrimps 9.4. [4] Mackerel 3.7; tunny 5.8. [5] Including hydroxypro

ıponent parts of the body changes with age, and the parts do all mature chemically at the same rate The composition of the ɔle body at any age ıs the resultant of the composition of its ues and of their contribution to the weight of the body at that

·thods of determining the composition of the whole body

Dilution methods depend upon introducing into the body a

ner cause, the volume of fluid in which the substance has become stributed can be calculated By the use of appropriate substances is possible to estimate the amounts of total water, of extracellular

ccording to the substance used, and the use of each involves certain ssumptions (for discussion of these see the literature[1])

* This chapter on the 'Composition of the Body' (pages 517–522) has been ompiled by E. M WIDDOWSON and J W T DICKERSON, Department of Experimental Medicine, University of Cambridge, England

amount of any mineral in the body but only that fraction of it which is 'exchangeable'.

Determination of the composition of the tissues

gans and tissues than about that of the body as a whole.

Changes in composition during development

The proportion of fat in the human body increases rapidly during the last 2 months of gestation and the full-term baby has about 16%.

ment is a decrease in the proportion of water in the fat-free body tissue and an increase in that of solid matter The fall in the proportion of total water is due to the large reduction in the amount of extracellular fluid that accompanies growth; this exceeds the small rise in the amount of water inside the cells due to the increase in the

skeleton and the proportion of calcium in the body more than doubles during postnatal life.

References

Composition of the whole body as determined by chemical analysis (values per kilogramme fat-free tissue unless otherwise stated)

	Body weight kg	Water* g	Fat* g	Water g	N g	Na mEq	K mEq	Cl mEq	Mg g	Ca g	P g	Fe mg	Cu mg	Zn mg	B mg	Co mg
Foetus	0 02	898	2	900	10 5	110	48	80	0.10	2 1	2 1	–	–	–	–	–
Foetus	0 20	876	5	880	13 0	102	42	76	0 14	3 5	2 5	54	3 3	20	–	–
Foetus	1 0	851	10	860	18 4	94	42	68	0 20	6 3	3 9	65	3.4	20	–	–
Foetus	2 0	790	60	840	21 0	88	45	62	0 24	7 8	4 8	84	4 0	20	–	–
Newborn, full-term	3 5	689	160	820	22 6	82	53	55	0 26	9 6	5 6	94	4.7	20	–	–
Adults	70	605	160	720	34 0	80	69	50	0 47	22 4	12.0	74	1.7	28	0.37	0 02

* Per kilogramme whole body weight

References

WIDDOWSON et al, *Clin Sci*, 10 113 (1951), WIDDOWSON and SPRAY, *Arch Dis Childh*, 26, 205 (1951), FORBES et al., *J biol Chem*, 203, 359, (1953), FORBES et al, *J biol Chem*, 209, 857 (1954), FORBES and LEWIS, *J clin Invest*, 35, 596 (1956), FORBES et al, *J biol Chem*, 223, 969 (1956), WIDDOWSON and DICKERSON, in COMAR and BRONNER (Eds), *Mineral Metabolism*, vol. 2, part A, Academic Press New York, 1964, page 1

Composition of the whole body as determined by dilution methods

	Total water as percentage of body weight	Extracellular fluid as percentage of body weight	Exchangeable Na mEq/kg body weight	Exchangeable K mEq/kg body weight	Exchangeable Cl mEq/k[g] body wei[ght]
Newborn, 1–27 hours[1]	–	–	–	35.5	–
Newborn, 1 day[2]	79.0 (deuterium oxide)	43.9 (thiosulphate)	–	–	–
Infants, 2–4 weeks[3]	–	–	–	–	48.1
Infants, 2 weeks–2 months[4]	–	–	76.4	–	–
Men[5]	59.1 (deuterium oxide)	15.6 (inulin)	41.7	48.1	31.9
	59.6 (tritium oxide)	16.3 (thiosulphate)	–	–	–
	53.4 (antipyrine)	22.9 (thiocyanate)	–	–	–
	60.2 (urea)	–	–	–	–
Women[5]	51.0 (deuterium oxide)	16.0 (thiosulphate)	40.5	38.2	28.6
	43.4 (antipyrine)	20.9 (thiocyanate)	–	–	–
	57.0 (urea)	–	–	–	–

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2 Friis-Hansen, B., *Acta paediat. (Uppsala)*, 46, suppl. 110 (1957).
3 Cheek, D.B., *Pediatrics*, 14, 5 (1954).
4 Forbes and Perley, *J.clin.Invest.*, 30, 566 (1951).
5 For details see Widdowson and Dickerson, in Comar and Bronne[r] (Eds.), *Mineral Metabolism*, vol. 2, part A, Academic Press, New Yor[k] 1964, page 1.

Composition of muscular tissues (values per kilogramme fat-free tissue)

		Weight as percentage of body weight	Water g	N g	Na mEq	K mEq	Cl mEq	Mg mEq	Ca mEq	[illegible] mn
Skeletal muscle[1]	Foetus, 14 weeks	–	907	11.5	101	56.3	76.4	11.7	5.6	36
	Foetus, 20–22 weeks	25	887	15.4	90.6	57.6	65.6	10.5	7.1	40
	Newborn	25	804	20.9	60.1	57.7	42.6	14.8	4.3	47
	Infants, 4–7 months	–	785	29.6	50.1	89.5	35.5	20.0	3.1	64
	Adults	43	792	31.4	36.3	92.2	22.1	16.7	2.8	58
Heart[2] Whole	Foetus, 20 weeks	0.6	860	14.0	46.1	81.1	41.0	–	–	49.
	Newborn	0.5	841	19.6	64.2	54.3	45.2	10.9	7.4	47.
	Infants, 4–7 months	–	830	21.0	59.8	49.3	49.3	11.0	8.2	49.
	Adults	0.4	827	22.9	57.8	66.5	45.6	13.2	2.6	49.
Left ventricle	Adults	–	789	–	44.7	78.5	38.0	17.0	3.9	63.
Right ventricle	Adults	–	802	–	47.8	56.2	39.5	16.5	3.8	50.
Auricles	Adults	–	812	–	52.2	35.7	42.2	–	–	30.
Septum	Adults	–	792	–	40.5	79.0	33.8	–	–	51.
Myometrium[3]	Non-pregnant	–	794	–	87.8	62.6	73.8	12.8	16.6	–
	Early pregnant	–	825	–	93.6	59.0	71.0	8.5	7.1	–
	At term	–	823	–	88.8	62.4	63.2	13.5	17.5	–

References

1 Dickerson and Widdowson, *Biochem.J.*, 74, 247 (1960).
2 Wilkins and Cullen, *J.clin.Invest.*, 12, 1063 (1933); Mangun et al., *Arch.intern.Med.*, 67, 320 (1941); Alexander et al., *J.Lab.clin.Med.*, 36, 796 (1950); Clarke and Mosher, *Circulation*, 5, 907 (1952); Widdowson and Dickerson, *Biochem.J.*, 77, 30 (1960).
3 Hawkins and Nixon, *J.Obstet.Gynaec.Brit.Emp.*, 65, 895 (1958).

Composition of glandular organs (values per kilogramme fresh weight)

		Weight as percentage of body weight	Water g	N g	Na mEq	K mEq	Cl mEq	Mg mEq	Ca mEq	P mmol	Fe (inorganic) mg	Cu mg	Zn mg	Mn mg
Liver[1-3]	Foetus, 14 weeks ..	–	849	20 2	–	81.8	62 2	–	–	82 5	–	–	–	–
	Foetus, 20 weeks .	4	812	22.1	54 8	92 9	57.1	14 7	2 3	88 0	–	–	–	–
	Newborn.........	5	786	22 6	59 8	58 7	55 8	10 4	3 0	56.5	300	41.5	68.6	0.9
	Infants, 4-7 months	4	764	24 4	51 0	66 2	42.8	11.8	4.4	82.5	170	8 6	–	–
	Adults	2	711	28.2	42.5	75 0	38 3	15.2	2 8	86.0	28–162	5.2	–	1.3
Kidneys[1 2 4]	Foetus, 20 weeks ..	0 7	884	14 2	68 0	66 5	59 6	8 6	17.4	65 5	–	–	–	–
	Newborn....	1 0	841	19.2	75 5	56 0	56 4	8.7	7 7	61 0	32	3 7	–	–
	Adults	0 5	810	24 5	82 0	57.0	67.8	8 6	7.0	57.5	3 3–10 1	2 8	–	–
Spleen[1 3 5]	Adults	0.2	790	30 1	–	81 0	–	13 0	4 2	71 0	85–169	1 8	33.0	0.18

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[1] Tompsett, S L., *Biochem J*, 29, 480 (1935)
[2] Brückmann and Zondek, *Biochem J*, 33, 1845 (1939)
[3] Widdowson et al, *Clin Sci*, 10, 113 (1951)
[4] Widdowson and Dickerson, *Biochem J*, 77, 30 (1960).
[5] Richards, M B, *Biochem J*, 24, 1572 (1930), Forbes et al, *J biol Chem*, 203, 359 (1953)

Composition of the lungs (values per kilogramme fresh tissue)

	Weight as percentage of body weight	Water g	N g	Na mEq	K mEq	Cl mEq	Mg mEq	Ca mEq	P mmol	Fe (total) mg	Cu mg	Mn mg	B mg	Co mg	Be µg
Foetus, 20 weeks	–	888	10 3	89 0	71 0	67 5	–	–	56 5	70	–	–	–	–	–
Newborn	1 7	858	17.0	75 6	48 6	62 5	–	–	44 0	150	–	–	–	–	–
Adults .	1 6	787	27 2	75 3	54 7	69 0	4 8	12 5	51 8	200	3 7	0 40	0 16	0 03	0.23

References

Richards, M B, *Biochem J*, 24, 1572 (1930), Chou and Adolph, *Biochem J*, 29, 476 (1935), Forbes et al, *J biol Chem*, 223, 969 (1956), Widdowson and Dickerson, in Comar and Bronner (Eds), *Mineral Metabolism*, vol 2, part A, Academic Press, New York, 1964, page 1

Composition of the brain and nerves (values per kilogramme fresh weight unless otherwise stated)

		Weight as percentage of body weight	Water g	N g	Na mEq	K mEq	Cl mEq	Mg mEq	Ca mEq	P mmol	Cu[3] mg	Fe[3] mg	Mn[3] mg	Pb[3] mg
Brain Whole[1]	Foetus, 14 weeks	15 0	914	9 6	97.5	49 6	72 1	–	–	57 0	–	–	–	–
	Foetus, 20–22 weeks	13.4	922	8 4	91.7	52 0	72 6	8 4	4 9	32 2	–	–	–	–
	Newborn	13 4	897	9 3	80 9	58 2	66 1	7 9	4 8	54 0	–	–	–	–
	Adults	2 3	774	17 1	55 2	84 6	40.5	11 4	4 0	109	3 6–50	–	–	–
Grey matter[2]	Adults	–	843	17.2	83 9	58 4	48 6	16 3	5 2	71 3	15 9–99 0* 19 4, 33 0**	328–461* 222**	1.12* 1 24**	0 4–17 3 –
White matter[2]	Adults	–	706	17.5	68 6	59 4	41 2	21 6	7 1	127	9 2–82 0* 23 3**	269–507*	0.99*	– –
Spinal cord[2]	Adults .	0 04	644	16 0	87.4	92 2	42 8	31 6	9 0	177	–	177	–	–
Peripheral nerve[2]	Adults ..	–	557	–	–	47 6	–	–	9 9	119	12.3	15,6	–	–

* Cerebrum
** Cerebellum.

References

[1] (Except values from Cu onwards) Widdowson and Dickerson, *Biochem J*, 77, 30 (1960)
[2] (Except values from Cu [illegible]
[3] [illegible]

Organic composition of the adult brain and spinal cord (values per kilogramme fresh tissue unless otherwise stated)[1]

	Whole brain g	Grey matter g	White matter g	Spina[l cord] g
Total phospholipid P	250*	30.8	78.2	51-
Lecithin P	–	7.9–13.2	9–15	22†
Cephalin P	148–260*	18–22	27–35	61†
Diphosphoinositide P	–	1.96	4.14	–
Sphingomyelin P	–	2.7	10.8	–
Cerebrosides	–	6.3 ± 2.9	49.0**	12.9–
		3.1 ± 0.2**		6[illegible]
Total lipids	104	57.9	179	–
Cholesterol	26–44	7.2	40.7	5[illegible]
Gangliosides (*N*-acetylsialic acid × 4.0)	–	3.3	1.25	–
Total protein	100–110	73–82	77–92	9[illegible]
Soluble in 4.5% KCl (isoelectric point pH 5.6)	–	16.7–18.9	18.5–22.1	–
Soluble in water (isoelectric point pH 4.6)	–	21.9–24.6	14.6–17.5	–
Proteolipid protein[2]	–	16	42	–
Neurokeratin	–	3.1	11.2	–

* Values per kilogramme dry weight.
** 'True' cerebrosides.
† Not expressed as P.
†† *White matter.*

References

[1] (Except proteolipid protein) Ansell, G.B., in Long, C. (Ed.), *B[iochem]ists' Handbook*, Spon, London, 1961, page 640.
[2] Approximate values calculated from Folch and Lees, *J.biol.Chem*[illegible] 807 (1951).

Composition of skin, hair and nails (values per kilogramme fresh weight unless otherwise stated)

		Weight as percentage of body weight	Water g	N g	Na mEq	K mEq	Cl mEq	Mg mEq	Ca mEq	P mmol	Cu mg	Fe mg	Mn** mg	Pb mg	
Skin[1]	Foetus, 14 weeks	–	917	11.6	–	23.8	90.6	–	4.4	41.8	–	–	–	–	
	Foetus, 20 weeks	13	901	11.9	120	36.0	96.0	3.8	6.1	28.2	–	–	–	–	
	Newborn	15	828	26.5	87.1	45.0	66.9	4.7	10.0	31.7	–	–	–	–	
	Infants, 3–5 months	–	675	54.5	65.4	43.7	72.3	7.4	11.4	34.9	–	–	–	–	
	Adults	7	694	53.0	79.3	23.7	71.4	3.1	9.5	14.0	–	–	–	–	
Epi-dermis[2]	Adults	–	645	–	49.6	81.4	–	15.0	7.5	–	–	–	–	–	
Hair*[3]	Adults	–	–	–	–	–	–	0.8–8.4	94–245	–	4–128	0.8–170	0.00001–46	17–508	15[illegible]
Nails*[4]	Adults	–	–	–	–	–	–	1.9–9.2	–	–	9–81	18–65	<1	97–240	170

* Hair and nails also contain Zn (9–562 and 116–3080 mg/kg respectively). The presence in hair of Al, Ni, Co and Cr together with traces of Ti, Sr and Ag has also been reported.
** Values per kilogramme dry weight.

References

[1] Widdowson and Dickerson, *Biochem.J.*, 77, 30 (1960).
[2] Suntzeff and Carruthers, *J.biol.Chem.*, 160, 567 (1945); Zhe[illegible] and Fox, *Arch.Derm.*, 61, 397 (1950).
[3] F[illegible] *the.* [illegible]
[4] C[illegible] cz, [illegible] Unive[rsity] of Chicago Press, Chicago, 1954, page 662.

Composition of teeth and bones (values per 100 gramme dry fat-free tissue unless otherwise stated)

		Water* g	N g	Ca g	P g	Mg g	CO_3^{--} g	Cl g	F g	Na g	K g	Fe g	Cu g	Pb g
Teeth[1]														
Enamel	Adults	3	0.03	36	17	0.4	2.5	0.25	0.010–0.034	0.71–0.90	0.05–0.30	0.0008–0.4	0.00017–0.0009	–
Dentine	Adults	10	3.4	27	13	0.9	3.3	0.00–0.03	0.024–0.076	0.30	0.07–0.10	0.007	–	0.005
Bone tissue[2]														
Cortex of femur	Foetus, 14 weeks	–	5.95	18.9	9.1	–	–	–	–	–	–	–	–	–
	Foetus, 20–24 weeks	31.1	5.25	23.4	10.5	–	–	–	–	–	–	–	–	–
	New born	23.8	5.06	24.6	10.8	–	–	–	–	–	–	–	–	–
	Infants, 2–4½ months	23.0	5.28	23.7	10.8	–	–	–	0.049**	–	–	–	–	–
	Infants, 5–9 months	19.5	5.31	24.9	11.0	–	–	–	–	–	–	–	–	–
	Infants, 12–24 months	20.3	5.24	24.6	11.1	–	–	–	0.071**	–	–	–	–	–
	Children, 12 years	15.5	4.92	25.3	11.5	–	–	–	–	–	–	–	–	–
	Adults, 18–35 years	12.2	4.74	26.4	11.3	0.39	4.0	0.18	0.094–0.270**	0.18–0.6	0.05–0.3	0.011–0.017	0.0002–0.0048	0.001–0.01
Whole femur (excluding epiphyses)	Foetus, 14 weeks	56.0	5.69	15.8	7.1	–	–	–	–	–	–	–	–	–
	Foetus, 20–24 weeks	54.6	5.95	19.1	8.2	–	–	–	–	–	–	–	–	–
	New born	48.8	5.94	23.6	9.9	–	–	–	–	–	–	–	–	–
	Infants, 2–4½ months	49.2	6.78	19.9	9.7	–	–	–	–	–	–	–	–	–
	Infants, 5–9 months	43.7	6.89	19.0	8.6	–	–	–	–	–	–	–	–	–
	Infants, 12–24 months	39.7	5.67	18.3	8.5	–	–	–	–	–	–	–	–	–
	Children, 12 years	30.7	5.21	27.2	12.4	–	–	–	–	–	–	–	–	–
	Adults, 18–35 years	22.7	5.20	25.1	10.7	–	–	–	–	–	–	–	–	–

* Per 100 gramme fat free bone
** Increases with age and with the amount in the drinking water. Values given are for ribs (JACKSON and WEIDMANN *J Path Bact*, 76, 451 [1958])

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[1] EASTOE, J E, in LONG, C. (Ed), *Biochemists' Handbook*, Spon, London, 1961, page 720
[2] EASTOE, J E, in LONG, C. (Ed), *Biochemists' Handbook*, Spon, London, 1961, page 715, DICKERSON, J W T, *Biochem J*, 82, 56 (1962)

Strontium and barium contents of ashed bone (µg/g)

Age	Sr	Ba
0–3 months	79.1	7.0
1–13 years	73.8	7.6
19–33 years	107	5.1
33–74 years	114	8.5

Reference

SOWDEN and STITCH *Biochem J*, 67, 104 (1957)

Strontium-90: calcium ratio in bone (pCi ^{90}Sr/g Ca)

Age	Mean	Maximum
0–5 years	2	3.2
5–20 years	1	2.0
Over 20 years	0.3	0.6

Reference

SCHEUERMANN, W, *Z Ernährungsw*, 2, 123 (1962) Values from Western Germany 1960

Organic components of soft and hard tissues (values per kilogramme fresh tissue unless otherwise stated)

		Non-protein N g	Sarcoplasmic protein N g	Fibrillar protein N g	Collagen N g	Glycogen g	Mucopoly-saccharides g	Cholest g
Skeletal muscle[1]	Foetus, 14 weeks	1.2	3.6	5.7	0.6 } Total extracellular protein N	–	–	–
	Foetus, 20–22 weeks	1.7	3.7	8.7	1.8	–	–	–
	Newborn	2.4	3.9	10.9	3.8	–	–	–
	Infants, 4–7 months	3.2	5.0	17.0	4.6	–	–	–
	Adults	3.0	6.7	19.9	1.4	–	–	2.7
Uterus[2]								
Muscle	Non-pregnant	–	–	5, 11, 4*	–	–	–	10**
	Pregnant, at term	–	–	13, 9, 15*	–	–	–	–
Mucous membrane	Proliferative phase	–	–	–	–	3.2	–	–
	Early differentiation phase	–	–	–	–	11.2	–	–
	Secretory phase	–	–	–	–	6.4	–	–
Skin[3]	Foetus, 20–22 weeks	–	–	–	2.4	–	–	–
	Newborn	–	–	–	16.8	–	2.9†	–
	Infants, 4–7 months	–	–	–	39.2	–	–	–
	Adults	–	–	–	45.7	–	2.0†	–
Bone[4]	Foetus, 14 weeks	–	–	–	29.2†	–	–	–
	Foetus, 20–24 weeks	–	–	–	40.6†	–	–	–
	Newborn	–	–	–	42.0†	–	–	–
	Infants, 2–4½ months	–	–	–	44.0†	–	–	–
	Infants, 5–9 months	–	–	–	42.7†	–	–	–
	Infants, 12–24 months	–	–	–	43.7†	–	2.3††	–
	Adults, 18–35 years	–	–	–	41.5†	–	1.6††	–
Teeth[5]								
Enamel	Adults	–	–	–	0.16**	–	1.0 (Soluble enamel protein)	–
Dentine	Adults	–	–	–	30.6–32.4**	–	2.0–6.0	4.0

* Values for actomyosin, myosin and actotropomyosin respectively.
** Per kilogramme dry tissue.
† Per kilogramme dry fat-free tissue.
†† Per kilogramme dry weight as glucosamine hydrochloride.

References
[1] Dickerson and Widdowson, *Biochem. J.*, 74, 247 (1960).
[2] Csapo, A., *Amer. J. Physiol.*, 160, 46 (1950); Naeslund and Snellman, *Acta Soc. Med. upsalien.*, 59, 349 (1954); Arronet and Latour, *J. clin. Endocr.*, 17, 261 (1957).
[3] Widdowson and Dickerson, *Biochem. J.*, 77, 30 (1960); Loewi, G., *Biochim. biophys. Acta*, 52, 435 (1961).
[4] Rogers, H. J., *Nature*, 164, 625 (1949); Dickerson, J. W. T., *Biochem. J.*, 82, 56 (1962).
[5] Eastoe, J. E., in Long, C., (Ed.), *Biochemists' Handbook*, Spon, London, 1961, page 720.

Composition of placenta and amniotic fluid (values per kilogramme fresh placenta and per litre amniotic fluid)

	Stage of gestation	Water g	N g	Na mEq	K mEq	Cl mEq	Mg mEq	Ca mEq	P mmol	Cu mg	Zn mg
Placenta[1]	20–40 weeks	866	18.5	98	40	–	6.6	12.4	30	1.5	10.0
Amniotic fluid[2]	First half	–	–	135	4.0	109	1.4	3.6	1.2	–	–
	Term	–	–	–	–	–	–	–	0.7	–	–

References
[1] Widdowson and Spray, *Arch. Dis. Childh.*, 26, 205 (1951); for further values see Berger and von Hornstein, *Fortschr. Geburtsh. Gynäk.*, 14, 1 (1961).
[2] Makepeace et al., *Surg. Gynec. Obstet.*, 53, 635 (1931); Economou-Mavrou and McCance, *Biochem. J.*, 68, 573 (1958); Westin et al., *Acta paediat. (Uppsala)*, 49, 154 (1960).

(For references see page 530)

his chapter on 'Water and Electrolyte Balance' has been com- d by U. F. GRUBER and M ALLGÖWER of the University Surgical ic, Basle It should be read in conjunction with the chapter on ueous Solutions', pages 270–271.

he treatment of water and electrolyte disturbances is a matter estoring a balance In healthy adults the total intake of each nent is equal to its total excretion. Treatment thus calls for a owledge of the daily water, electrolyte and caloric requirements he adult and of the ways and amounts in which they are excreted. patients it is necessary to take into account not only the daily ikes but also the amounts of water and electrolytes which have n and are being excreted. The success of treatment is therefore endent on *precise determination of the total intake (food, drink,* [illegible]

[illegible]

der standardized conditions It is essential to rectify the whole ctrolyte and water balance of the patient, the mere correction of ticular abnormal plasma concentrations does not suffice.

mposition of the body

This is shown in detail in the chapter 'Composition of the Body' pages 517–522.

ble 1 Approximate composition of the whole body and distribution of the body water expressed as percentage of the body weight

	Adults		Infants
	Men	Women	
Solids	40	50	25
Organic substances	35	45	–
Minerals	5	5	–
Total body water	60	50	75
Intracellular .	40	30	40
Extracellular	20	20	35
(a) intravascular	4	4	5
(b) interstitial	16	16	30

Electrolyte composition of the body fluids

For a more detailed discussion of the serum electrolyte composition see under 'Blood', page 561 sq.

Table 2 Concentrations of the principal electrolytes in serum, serum water and the interstitial and intracellular fluids[1]

	Serum		Serum water	Interstitial fluid*	Intracellular fluid**
	mEq/l	mg/l	mEq/l	mEq/l	mEq/kg water
Cations					
Sodium	142	3265	152.7	145	10
Potassium	4	156	4 3	4	160
Calcium	5	100	5 4	5	2
Magnesium	2	24	2 2	2	26
Cations, total	153	3545	164 6	156	198
Anions					
Chloride	*101*	*3581*	*108.5*	*114*	3
Bicarbonate	27	1648	29.3	31	10
Phosphate ($HPO_4^=$) .	2	96	2.2	2	100
Sulphate	1	48	1	1	20
Organic acids	6	210	6.4	7	–
Proteins	16	66300	17 2	1	65
Anions, total.......	153	71900	164.6	156	198

[illegible]

ble 3 Conversion factors for serum electrolytes (see also page 276)

	Serum concentrations				Conversion factors			
	mEq/l	mmol/l	mosm/l	mg/l	mg/l to mEq/l	mg/100 ml to mEq/l	mEq/l to mg/l	mEq/l to mg/100 ml
Cations								
Sodium	142	142	142	3265	0 0435	0 435	23 0	2.30
Potassium	4	4	4	156	0 0256	0 256	39.1	3.91
Calcium	5	2 5	2 5	100	0 0499	0 499	20 0	2.00
Magnesium	2	1	1	24	0 0823	0 823	12.2	1.22
Cations, total	153	149 5	149 5	3545	–	–	–	–
Anions								
Chloride	101	101	101	3581	0 0282	0 282	35.5	3.55
Bicarbonate	27	27	27	1648	0 0164*	0 164*	61.0*	6.10*
Phosphate ($HPO_4^=$)	2	1	1	96	0 0208	0.208	48 0	4 80
Sulphate	1	0 5	0 5	48	0 0208	0.208	48 0	4.80
Organic acids	6	6	6	210	0 0286	0.286	35	3.5
Proteins	16	2	2	66300	0 000241**	0 00241**	4145**	414.5**
Anions, total	153	137.5	137 5	71900	–	–	–	–
Total cations + total anions	306	287	287	75400	–	–	–	–

* For the conversion of vol% CO_2 into mmol CO_2 and vice versa see page 276

** The VAN SLYKE factor of 2 41 for the conversion of serum protein (g/100 ml) into ionized serum protein (mEq/l) is valid for 38 °C, pH 7 4 and an albumin/globulin ratio of 1 6 When the distribution of the plasma protein fractions is abnormal, VAN SLYKE recommends calculation of the equivalent value for the albumins and globulins by means of the following factors[2]: 1 g albumin nitrogen = 1 745 mEq, 1 g globulin nitrogen = 1 205 mEq According to BROCH[3] these factors give values that are too high

(For references see page 530)

Water balance

Table 4 Average daily water turnover of an adult weighing 70 kg[4]

	Water intake (g) Obligatory	Water intake (g) Facultative		Water output (g) Obligatory	Water output (g) Facultative
Drink	650	1000	Urine	700	1000
Food	750		Skin	500	
Oxidative	350		Lungs	400	
			Faeces	150	
Subtotal	1750	1000	Subtotal	1750	1000
Total	2750		Total	2750	

Table 5 Daily water requirements in millilitres per kilogramme body weight at various ages under normal conditions[5,6]

Age	Body weight kg	Estimated water requirement ml/kg
3 days	3.0	80–100*
10 days	3.2	125–150*
3 months	5.4	140–160
6 months	7.3	130–155
9 months	8.6	125–145
1 year	9.5	120–135
2 years	11.8	115–125
4 years	16.2	100–110
6 years	20.0	90–100
10 years	28.7	70–85
14 years	45.0	50–60
18 years	54.0	40–50
Adults[7]	70.0	21–43

* Average value for breast-fed infants.

In adults, the daily water, electrolyte and calorie requirements can be calculated with sufficient accuracy from the body weight. In spite of the greater accuracy of values derived from body surface area this method offers no advantage since the actual requirements are also subject to other factors like age, sex, the functional state of the heart, kidneys and lungs, fever, disease, nutritional status and calorie consumption. In newborn as well as older children, however, the requirements should be calculated from the body surface area (see the nomogram on page 538) or the daily caloric turnover.

Table 6 Daily water requirements per square metre body surface area[6]

Minimum requirement	870 ml/m²
Average requirement	1500 ml/m²
Maximum tolerance	2730 ml/m²

Table 7 Average daily water turnover per 100 kcal[7]

Water intake	80–110 ml/100
Water of oxidation	10– 20 ml/100
Urine	50– 70 ml/100
Insensible water loss (see also Table 8)	40– 60 ml/100

Table 8 Average daily insensible water loss at different age

Age	ml/m²	ml/10[illegible]
0–3 years	1150	5[illegible]
3–8 years	950	4[illegible]
8–16 years	700	4[illegible]
Adults	550	4[illegible]

At body temperatures above normal the insensible wate[illegible] increases by about 13% for each degree Centigrade[8] (7% fo[illegible] degree Fahrenheit). For the water loss by sweating see page 6[illegible] resting infants under 12 months the pulmonary water loss am[illegible] to about 1 g/kg body weight per hour[5].

With normal bodily activity 25% of the total heat loss [illegible] body is accounted for by evaporation of water (insensible [illegible] loss)[9]. The heat of evaporation of water is 0.58 kcal/ml (or 1 [illegible] 1.7 ml) at 37 °C, whence the water loss by evaporation can b[illegible] culated from the total calorie expenditure.

Table 9 Water of oxidation[7]

Metabolic breakdown of	gives rise to
100 g fat	107 ml water o[illegible]
100 g protein	41 ml water o[illegible]
100 g carbohydrate	55 ml water o[illegible]
100 g nonfatty tissue	15 ml water of [illegible]

That the proteins of nonfatty tissue are not fully oxidiz[illegible] by the presence of a nonoxidized C-atom in the urea ex[illegible] the urine. The breakdown of nonfatty tissue not only giv[illegible] water of oxidation but also releases the intracellular water [illegible] 100 g). Fatty tissue contains practically no water[10].

Table 10 Water arising from metabolic breakdown of body [illegible]

Metabolic breakdown of	gives rise to	
500 g fatty tissue	535 ml water of oxidation	–
500 g nonfatty tissue	75 ml water of oxidation	365 ml intracellul[illegible] water
1000 g fatty and nonfatty tissue together	610 ml water of oxidation	365 ml intracellul[illegible] water
	Total: 975 ml water	

The breakdown of 1 kg of the body's own tissue, assuming made up of equal parts of fatty and nonfatty tissue, thus gives to about 1 l of endogenous, practically sodium-free water. I[illegible] important that this should be allowed for in patients with a [illegible] calorie consumption whose water excretion is low (e.g., after [illegible] tions), since otherwise they may easily become waterlogg[illegible] patient given only electrolytes and 5% glucose solution af[illegible] uncomplicated abdominal operation should therefore lose 20[illegible] weight per day[10].

(For references see page 530)

...ctrolyte balance

...le 11 Daily requirements, usual intake and average excretion of various electrolytes[1,7,10,11]

	Minimum requirement* mEq/day	Usual intake mEq/day	Average excretion** With an intake of mEq/day	Urine mEq/day	Faeces mEq/day	Su... mE...
Sodium						
Adults	20	50–250	100	97	3	0–
Per square metre body surface	12	29–145				
Per kilogramme body weight	0 3	0.7–3 6				
Potassium						
Adults	20–33	50–150	100	90	10	0–
Per square metre body surface	12–19	29–87				
Per kilogramme body weight	0 3–0 5	0.7–2 1				
Calcium						
Adults	15	25–75	50	5	45	
Per square metre body surface	9	14–43				
Per kilogramme body weight	0 2	0.4–1.1				
Magnesium						
Adults	16–25	20–50	30	10	20	
Per square metre body surface	9–14	12–29				
Per kilogramme body weight	0 2–0 4	0 3–0 7				
Chloride						
Adults	20	50–250	100	97	3	0–
Per square metre body surface	12	29–145				
Per kilogramme body weight	0 3	0.7–3 6				

** For details see under 'Urine', pages 662–664, 'Faeces', page 65... 'Sweat', pages 679–680

Table 12 Amounts and electrolyte contents of important body fluids*

	Amount	Sodium mEq/l	Potassium mEq/l	Chloride mEq/l	Bicarbonate mEq/l	pH
Saliva	500–1500 ml/24 h	10–25	15–40	10–40	2–13	–
Gastric juice	2000–3000 ml/24 h	–	–	–	–	–
with parietal-cell secretion	–	20–70	5–15	80–160	0	acid
without parietal-cell secretion	–	70–150	5–15	80–120	25–40	neutral to weakly al...
Pancreatic juice	300–1500 ml/24 h	140	6–9	110–130	25–45	alkaline
Bile	250–1100 ml/24 h	130–165	3–12	90–120	30	weakly alkaline
Intestinal secretions	3000 ml/24 h	–	–	–	–	weakly alkaline
Small intestine, MILLER-ABBOTT tube	–	82–148	2–8	43–137	–	–
Ileostomy, recent	–	105–144	6–29	90–136	–	–
Ileostomy, adapted	–	46	3	21	–	–
Caecostomy	–	53	8	–	–	–
Intraluminal fluid	500 ml	70	35	–	–	–
Sweat	500–1000 ml/24 h	5–80	5–15	5–70	–	–
Cerebrospinal fluid	100–160 ml	130–150	2 5–4 5	122–128	25	weakly alkaline
Transudates**	–	130–145	2 5–5	90–110	–	–
Faecal water***	–	–	–	–	–	–

* These data are discussed more fully in the later chapters dealing with the individual body fluids The values for the intestinal secretions and transudates are from LOCKWOOD and RANDALL[12], those for the intraluminal fluid from BLACK[13]

** The ratios of the electrolyte concentrations in transudate water to those in serum water amount on the average to 0 96 for sodium, 0 92 for potassium

(For references see page 530)

Table 13 Sodium and potassium exchange in a man weighing 70 kg[10,16]

	Sodium	Potassium
Total exchangeable*	2800 mEq	3400 mEq
In plasma..........	450 mEq	14 mEq
In interstitial fluid ..	1900 mEq	60 mEq
In intracellular fluid .	220 mEq	3300 mEq
Average intake	100 mEq/24 h**	100 mEq/24 h***
Average excretion ..	100 mEq/24 h	100 mEq/24 h
1 mEq corresponds to	23 mg	39 mg

* Including sodium in the bones, which is not otherwise included in the table. For further details see 'Composition of the Body', page 518.
** 1 l of physiological (isotonic) salt solution (0.85%) contains 145 mEq each of sodium and chloride, which is more than the daily requirement of salt.
*** 60 mEq/day is adequate if given parenterally and kidney function is unimpaired[10]. Patients with healthy kidneys can safely be given infusions of 20–25 mEq potassium per hour; in severe potassium deficiency it may be necessary to give 50–60 mEq per hour[16].

Osmotic relationships

The distribution of water and its solutes in the water spaces of the body is a result of the osmotic relationships. The membranes separating the various fluid phases of the body (the vascular endothelium and the cell membranes) are in general freely permeable to water, so that there is a uniform osmotic pressure throughout the body fluids. For a discussion of freezing-point depression, osmotic pressure, osmolarity and osmolality see pages 270–271. For conversion tables see pages 272–273.

Freezing-point depression of plasma at 38 °C: 0.540 °C
Osmotic pressure of plasma at 38 °C: 7.39 atm (5616 mm Hg)
Osmolality of plasma at 38 °C: 291.2 mosm/kg water

The theoretical osmolality of blood plasma calculated from its known components and assuming their complete electrolytic dissociation is 325 mosm/kg serum water. The difference between this value and the actual osmolality of 291.2 mosm/kg serum water (the numerical value is about twice that of the sodium concentration in serum in mEq/l) is due to the fact that the electrolytes are not completely dissociated in serum.

Tonicity. From the clinical standpoint, tonicity and osmolality are the same thing. A solution is described as *isotonic* when it is ·osmotic with serum, i.e., has the same osmotic pressure as serum. practice, both hypotonic and hypertonic solutions with osmolali- ranging from 140 to 1710 mosm/kg water can be administered ··· ously without causing haemolysis[1]. $^1/_6$ molar, or $^1/_6$ normal, solutions of all salts having binary dissociation can be regarded for practical purposes as isotonic (333 mosm/l).

The maintenance of the plasma volume and the distribution of fluid between the plasma and the interstitial space is mainly dependent on the 'effective' osmotic pressure of the plasma proteins. The capillary endothelium is freely permeable to almost all the substances in solution in the extracellular fluid, the total osmotic pressure of which is determined mainly by the sodium and chloride ions. However, since these ions pass freely through the capillaries and become uniformly distributed by diffusion and filtration throughout the extracellular space they cannot contribute to the osmotic pressure gradients between the intravasal and extravasal spaces. On the other hand, the intravasal space contains almost all the large protein molecules. As a result of their effective osmotic pressure, these molecules prevent the passage of water out of the plasma in spite of the fact that they are responsible for only a small part of the total osmolality. This specific effect of the plasma proteins is known as the *colloid-osmotic* or *oncotic pressure.*

Oncotic pressure of plasma at 38 °C:	ca. 0.04 atm
	ca. 30 mm Hg
	ca. 400 mm H_2O

The albumins contribute about 85% of the colloid-osr sure. Since fibrinogen has practically no osmotic effect its high molecular weight the colloid-osmotic pressure can be assumed to be the same as that of plasma.

When the composition of the plasma proteins is abr colloid-osmotic pressure can be calculated by means of tl of Keys[17]:

Colloid-osmotic pressure (in mm H_2O) $\approx f_c\,(4.52\,A + 1.886\,G) \times$:

where A = albumin concentration in g/l, G = globulin c tion in g/l, T = absolute temperature in kelvin (K) = 27: f_c = a factor whose value depends on the total protein c the serum as follows:

Total protein content of serum (g/l)	10	20	30	40	50	60	
f_c	0.88	0.92	0.98	1.03	1.09	1.17	1

The colloid-osmotic pressure is counteracted by the hy pressure in the capillaries.

Capillary pressure at 3[illegible] C (see also page 553):

Arterial limb	32 mm
	435 mı
Venous limb..........................	12 mm
	163 mı

For osmotic activity of serum electrolytes see Table 3, ļ

Table 14 Osmotic activity of serum crystalloids[10]

1000 mg glucose/l serum	5.5 n
1000 mg urea/l serum	17.2 n

Table 15 Osmotic activity of serum colloids[10]

	g/l	mEq/l
Albumin	45	14
Globulin	15	2
Total proteins.................	60	16

Infusions of plasma and blood are distributed througl intravascular space, those of isotonic electrolytes througl extracellular space, those of isotonic crystalloid solutior glucose solutions) throughout the total body water.

Calorie requirements

The definition of the caloric and conversion tables will b on pages 212–213, the daily caloric requirements on page · calorific values of foods on pages 498–515, and the calorific of fats, proteins and carbohydrates on page 539.

The caloric requirements in parenteral infusion therapy met by solutions of carbohydrates and amino acids and by em of fats. Commercial preparations of known calorific va available.

The human body cannot normally utilize more than ca D-glucose per kilogramme body weight per hour[18].

Ethyl alcohol 95 vol% furnishes 5.6 kcal/g, lactate 0.31 kca 250 ml of plasma contain 15 g protein, equivalent to ca. 6

The total calorie consumption and expenditure of a h patient who is not bedridden but whose activity is limited ar to approx. 2000 kcal per day.

(For references see page 530)

Table 16 Daily calorie balance of a man weighing 70 kg[19]

Average intake		Average excretion	
500 g fat + carbohydrate + protein; 550 l oxygen		12 g urea nitrogen; 450 l carbon dioxide; 300 ml water of oxidation	
	Energy in kcal		Energy in kcal
Fat	900	Bodily activity (light) .	800
Carbohydrate..	1400	Specific dynamic effect .	200
Protein	300	Basal metabolism	1600
Total.........	2600	Total........	2600

cid-base balance and pH

The concentration of hydrogen ions in the various water compartments of the body is determined by the amounts and proportions of acids and bases present*. It is maintained within definite limits

[illegible]

resent, changes in the electrolyte content of the body fluids often cause changes in pH and vice versa

Table 17 Buffer capacity (ΔmEq/ΔpH) of the body tissues[20]

Tissue	Buffer capacity per kilogramme tissue	Kilogramme tissue per kilogramme body weight	Buffer capacity per kilogramme body weight
Blood	18	0 10	1.8
Muscle	5	0 65	3 25

Table 18 Relative buffer capacity of blood[21]

Whole blood 100%	Cells	79%		
	Plasma	21%	Ionized protein	13 6%
			Bicarbonate	6 1%
			Phosphate	1 5%

On a normal mixed diet the body has a positive hydrogen-ion balance The hydrogen ions arising from the breakdown of foods [illegible]

* According to the Brønsted-Lowry definition, acids are proton donors (hydrogen donors), bases proton acceptors.

$$\mathrm{pH} = 6\,10 + \log \frac{[\text{total } CO_2]_P - 0\,0301\, P_{CO_2}}{0\,0301\, P_{CO_2}}$$

where $[\text{total } CO_2]_P$ = sum of the concentrations of dissolved CO_2 and HCO_3^- in the plasma (P = plasma) in mmol/l. Conversion into vol% is made as follows (see page 276):

$$\text{mmol/l} = \frac{\text{vol\%}}{2.226}$$

The sum of the concentrations of dissolved CO_2 and H_2CO_3 in the plasma (in mmol/l) can be calculated from the formula:

$$[CO_2]_P = 0.0301\, P_{CO_2}$$

The concentration of HCO_3^- in the plasma (in mmol/l) is obtained as the difference between the total CO_2 concentration and the concentrations of dissolved CO_2 and H_2CO_3:

$$[HCO_3^-]_P = [\text{total } CO_2]_P - [CO_2]_P$$

These relationships are shown diagrammatically in Figure 1 (page 528).

Table 19 Normal values for the CO_2-bicarbonate system in the arterial and venous blood of adults?* [25] [27]

	Unit	Blood sample**	Mean	Range
pH	–	v	7.37	7.32–7.42
		a	7.40	7.35–7.45
$[HCO_3^-]_P$***	mmol/l	v	26	24–28
		a	24	22–26
P_{CO_2}	mm Hg	v	46	42–55
		a	40	34–46
$[\text{total } CO_2]_P$	mmol/l	v	27	25–29
		a	25	23–27
$[CO_2]_P$	mmol/l	v	1 38	1.26–1.65
		a	1 20	1.02–1.38

* For persons living at sea level [illegible]

** a = arterial blood, v = venous blood [illegible]

The respiratory components of the acid-base balance are adequately expressed by the P_{CO_2} value, whether the metabolic components are best expressed by the plasma bicarbonate content[28], by the buffer base content of the whole blood[29] (see page 571), or by the base excess of the whole blood[30] (see page 571) is a matter of discussion[31].

The following changes in acid-base balance are distinguished on the basis of the origin of the disturbance:

1. Respiratory alkalosis. Decrease in P_{CO_2} as a result of hyperventilation
2. Respiratory acidosis: Increase in P_{CO_2} as a result of reduced CO_2 excretion by the lungs

(For references see page 530)

3. Metabolic alkalosis: Increase in the base content or decrease in the acid content of the blood.
4. Metabolic acidosis: Increase in the acid content or decrease in the base content of the blood.

Two of these disturbances may appear at the same time (cf. Fig. 2).

Fig. 1 Nomogram for the evaluation of the HENDERSON-HASSELBALCH formula[26]

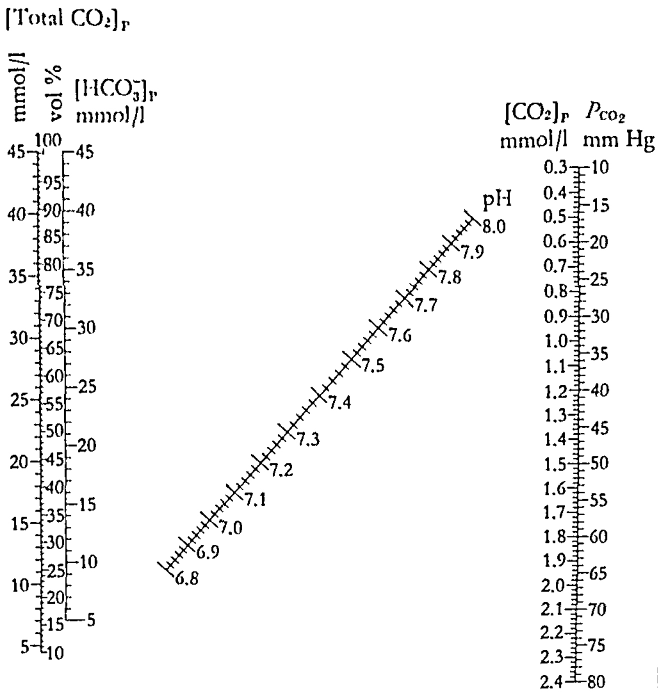
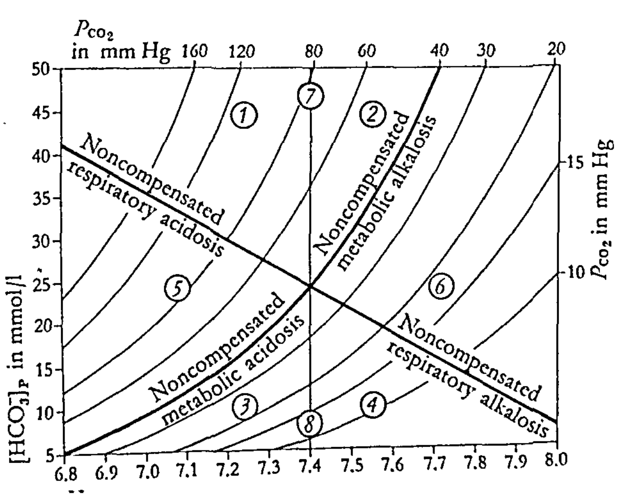


Fig. 2 The pH-bicarbonate diagram of DAVENPORT[25] as modified by PERRET[32]

The heavy line running from upper left to lower right is the normal plasma buffer curve, that running from lower left to upper right the P_{CO_2} isobar for normal plasma (40 mm Hg); other P_{CO_2} isobars are shown by thinner lines. The point of intersection of the plasma buffer curve and the 40 mm Hg isobar represents blood with the normal values pH = 7.40, bicarbonate concentration = 24 mmol/l, P_{CO_2} = 40 mm Hg.

The numbers in the diagram denote areas in which there is disturbance of acid–base balance: *1* Compensated respiratory acidosis. *2* Compensated metabolic alkalosis. *3* Compensated metabolic acidosis. *4* Compensated respiratory alkalosis. *5* Respiratory and metabolic acidosis. *6* Metabolic and respiratory alkalosis. *7* Fully compensated respiratory acidosis or metabolic alkalosis. *8* Fully compensated metabolic acidosis or respiratory alkalosis.



Blood volume

Table 20 Blood volume in health*[10]

Body build	Blood volume as perce of body weight	
	Men	Wom
Normal	7.0	6.5
Obese	6.0	5.5
Thin	6.5	6.0
Muscular	7.5	7.0

* Based on measurements of absolute blood volume made by separate simultaneous determination of plasma volume and red cell volume us two different tracer substances and addition of the results. For a detai discussion of blood volume see pages 554–555.

Body surface area

Table 21 Surface area of various parts of the body as percen of total body surface[33]

Age in years	Head	Trunk*	Arms**	Le
0	19	34	19	2
1	17	34	19	3
5	13	34	19	3
10	11	34	19	3
15	9	34	19	3
Adults	7	34	19	4

* Including the neck, genitals and buttocks.
** At all ages the palm of the hand is about 1% of the total body surfac

Table 22 Rule of nines for adults*[34]: Surface area of various p of the body as percentage of total body surface

Head	
Arms, each	
Trunk, front	1
Trunk, back	1
Legs, each	1
Genitals	1
Total	10

* The buttocks are included in the lower limbs. The proportions are sufficiently accurate for clinical purposes.

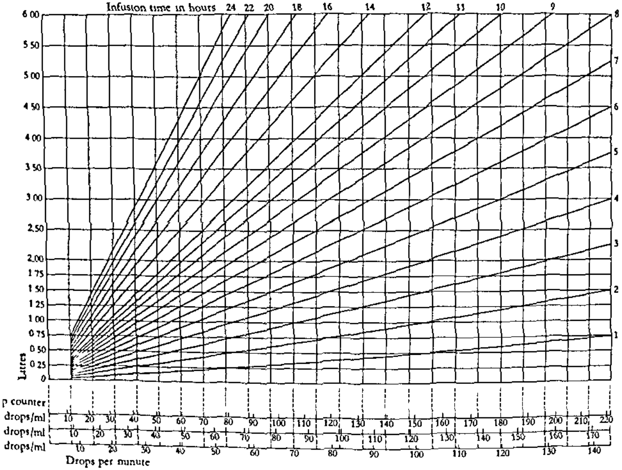
Parenteral therapy

Patients should be fed by mouth as soon as this is feasible. Wh intravenous water and electrolyte infusions are necessary at le part of the patient's nourishment should be by mouth if possib

Infusions should not be given subcutaneously; absorption slow and irregular (diffusion of ions and water), the procedure painful, the amount of fluid that can be given limited, and the ri of infection greater than when the intravenous route is used. more than one infusion must be given, early installation of intravenous tube is advisable. In the event that the tube must be le in situ for several days it is best to use the cephalic, basilic or jugul vein and introduce it as far as the superior vena cava. This metho appears to involve less risk of thrombosis than the use of th saphenous vein and the inferior vena cava. The smaller veins the arms or legs can be used, however, if the infusion is of sho duration and the solutions are more or less isotonic.

I Nomogram for number of drops per minute[35]

The number of drops per minute required to administer a particular quantity of infusion solution in a certain time can be read off directly from this nomogram. The nomogram allows for the increase in drop size as the dropping rate increases and is based on the normal drop defined by the relationship 20 drops distilled water at 15 °C = 1 g (± 0.05 g) when falling at the rate of 60/min The dependence of drop size on dropping rate is allowed for by the increasing width of the scale units of the three abscissae as the dropping rate increases



ble 23 Composition of some important parenteral infusion solutions

Solution	Solutes	g/l	Na⁺ mEq/l	K⁺ mEq/l	Ca⁺⁺ mEq/l	Mg⁺⁺ mEq/l	Cl⁻ mEq/l	HCO_3^- mEq/l	Lactate mEq/l	Total ions mEq/l	mosm/l	kcal/l
Glucose 5%	$C_6H_{12}O_6$	50	–	–	–	–	–	–	–	–	278	200
Salt 0.85%	NaCl	8.5	145	–	–	–	145	–	–	290	290	–
RINGER (USP)	NaCl	8.6	147	–	–	–	147	–	–	–	–	–
	KCl	0.3	–	4	–	–	4	–	–	–	–	–
	$CaCl_2 + 2H_2O$	0.33	–	–	5	–	5	–	–	–	–	–
	Total	–	147	4	5	–	156	–	–	312	309	–
RINGER lactate (HARTMANN)	NaCl	6.0	103	–	–	–	103	–	–	–	–	–
	KCl	0.4	–	5.4	–	–	5.4	–	–	–	–	–
	$CaCl_2 + 6H_2O$	0.2	–	–	1.8	–	1.8	–	–	–	–	–
	Na lactate	3.05	27	–	–	–	–	–	27	–	–	9
	$MgCl_2$	0.2	–	–	–	2	2	–	–	–	–	–
	Total	–	130	5.4	1.8	2	112.2	–	27	278.4	276	9
Sodium bicarbonate 1/6 normal	$NaHCO_3$	14	167	–	–	–	–	167	–	334	334	–
Ammonium chloride 1/6 normal	NH_4Cl	9	–	–	–	–	169	–	–	338	338	–

Table 24 Order of priority in the parenteral therapy of acute disturbances of water and electrolyte balance[10]

1. Maintenance of blood volume	5. Administration of potassium (see Table 13)
2. Maintenance of colloid-osmotic pressure	6. Total body water and electrolytes: maintenance of requirements and elimination of deficits
3. Restoration of acid-base balance	7. Provision of calories
4. Restoration of total osmotic pressure	

A great variety of crystalloid and electrolyte solutions of known constitution are commercially available. The tendency is now to restrict parenteral infusion therapy to a minimum number of basic solutions meeting the daily water and electrolyte requirements. Ampoules containing other electrolytes are available for mixing with these solutions if the need arises. Potassium chloride and lactate, sodium chloride, bicarbonate and lactate, calcium chloride, magnesium sulphate and others are supplied in this form.

Metabolic disturbances of acid-base balance mostly require treatment with sodium bicarbonate, sodium lactate, ammonium chloride or arginine hydrochloride. An effective intracellular buffer is also now available in the form of tris-hydroxymethylaminomethane (THAM). Its 0.3-molar solution (36.3 g/l) is isotonic and is usually given at a dosage of 0.3–0.5 g/kg body weight over 3–4 hours[36].

The following colloidal solutions are in common use in parenteral infusion therapy:

1. Whole blood: available as stored citrated blood, fresh citrated blood, fresh blood drawn over cation exchangers, fresh heparinated blood, or blood given by direct transfusion.
2. Red-cell concentrates: in their own plasma or in isotonic electrolyte solutions.
3. Plasma and plasma fractions: available as dried human plasma (not free of hepatitis virus), pasteurized plasma protein solutions, fresh plasma, or solutions of albumin, fibrinogen, antihaemophilic globulin and gamma globulin.
4. Plasma expanders in the form of dextran solutions (average molecular weight of either 70 000 or 40 000).

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(For references see page 536)

The individual functions of the kidneys can be assessed by means of quantitative as well as so-called semiquantitative tests. The quantitative tests are mostly based on the clearance principle and their use is not in all cases practicable or necessary; some are very time-consuming and may involve referring the patient to a specialized clinic. The semiquantitative tests include determinations of nonprotein nitrogen (NPN) and 'true' endogenous creatinine in the plasma, the phenolsulphonphthalein (PSP) test, and the fluid deprivation test for determining the ability of the kidneys to concentrate urine. The sensitivity of semiquantitative tests can be established by comparing their results with those of precise quantitative methods of determining the renal functions concerned

Renal haemodynamics

Quantitative methods

In these tests the plasma clearance (C)[1,2] of certain substances is calculated by means of the formula:

$$C = \frac{U \times V}{P} \qquad (1)$$

where U and P are the concentrations of the clearance substance in

[illegible]

recently been shown[7] that a poly(fructose)saccharide resembling

[illegible]

On account of its physicochemical and physiological properties, *p-aminohippuric acid* (PAH) is superior to all other substances for the determination of the *effective renal plasma flow* (C_{PAH})[2,8]

$$C_{PAH} = \frac{U_{PAH} \times V}{P_{PAH}} \qquad (2)$$

The total renal plasma flow[2] is

$$RPF = \frac{C_{PAH}}{E_{PAH}} \qquad (3)$$

E_{PAH} is the renal extraction $E_{PAH} = \frac{Ka - Kv}{Ka}$

where Ka is the concentration of PAH [illegible]

The effective renal blood flow[2] $= \frac{C_{PAH}}{1 - Ht}$ (4)

(Ht = peripheral haematocrit value)

The total renal blood flow[2] is

$$RBF = \frac{C_{PAH}}{E_{PAH}(1 - Ht)} \qquad (5)$$

The 'normal' values of the [illegible]

$$FF = \frac{C_{In}}{C_{PAH}} \qquad (6)$$

The clearances are increased on a protein-rich diet[14], as they are without any characteristic change in the filtration fraction [illegible]

portion, so that the filtration fraction remains practically unchanged The standard values at any age are given by the following equations:

$C_{In} = 157\ 0 - (1.16 \times \text{age in years})$
$C_{PAH} = 820\ 2 - (6\ 75 \times \text{age in years})$

The renal fraction of the minute output of the heart amounts normally to about 20%[2].

Semiquantitative methods

There exists no simple linear relationship between the glomerular

[illegible]

healthy kidneys[6] and may fail to react to a reduction in the glomeru-

[illegible]

body, since it is in this tissue that most of the creatinine is formed[22]. In determining plasma creatinine care should always be taken that

[illegible]

vidual variations but is of the order of 15%[17, 23], are a disturbing factor in the test, whereas in renal insufficiency their importance becomes less in inverse proportion to the true plasma creatinine level

Table 1 Normal values in renal haemodynamics (based on a body surface area of 1 73 m²)

1 Normal conditions (mixed diet, urinary volume 1–3 ml/min)		
Women[2]	C_{In}	108 8 ± 13 5 ml/min
	C_{PAH}	592 ± 153 ml/min
	FF	0 194 ± 0 039
	RBF[f]	982 ± 184 ml/min
Men[2]	C_{In}	124 1 ± 25.8 ml/min
	C_{PAH}	654 ± 163 ml/min
	FF	0 192 ± 0 035
	RBF[f]	1209 ± 256 ml/min
Men and women[11]	C_{In}	124 5 ± 9.7 ml/min
	C_{PAH}	638 6 ± 84 5 ml/min
	FF	0 197 ± 0 018
	RBF[12]	1165 ml/min
2. Hydration (urinary volume 6–12 ml/min)		
Men and women[11]	C_{In}	152 6 ± 14 7 ml/min
	C_{PAH}	711.7 ± 136 5 ml/min
	FF	0 220 ± 0 037
3 Steady state in dietetic restriction of sodium to 30 mEq/day, protein intake 0 5–1 0 g/kg body weight/day, urinary volume 1–3 ml/min		
Men and women[11]	C_{In}	107 6 ± 11 4 ml/min
	C_{PAH}	631.2 ± 87 8 ml/min
	FF	0 172 ± 0 018

* This chapter on 'Renal Function Values' has been compiled by D P MERTZ and H SARRE, Medical Policlinic University of Freiburg i B (Director Prof H SARRE)

(For references see page 536)

The upper limit of the normal range of *plasma NPN concentration* . considered to be 40 mg/100 ml[24]. Increases in this level are nown to be dependent on an increase in the *urea fraction*. The proortion of the NPN due to the urea fraction can be calculated oughly from the urea nitrogen by means of the formula of PETERS nd VAN SLYKE[25]:

NPN (in mg/100 ml) = 10 + (1.07 × urea-N in mg/100 ml).

Here it should be borne in mind that in chronic renal insufficiency ne rise in the NPN is not due to urea nitrogen to the extent indicated by the above formula. Whereas in acute renal failure up 90% of the NPN is represented by urea, in chronic renal insufficien there is a relatively larger increase in other NPN components.

The 15-minute *phenolsulphonphthalein test* (after a single i.v. inje tion of 6 mg of the dye) is not sufficiently sensitive to reveal sm changes in the excretory function of the renal tubules[26]. Tl marked variance of the sample values around the regression li (Fig. 3) is due in the main to the combination of PSP with plasn proteins (dependent on various factors), the absence of a flo

ig. 1 Nonlinear relationship between the concentration of 'true' endogenous creatinine in plasma (P_{Cr}, as measured by the method (LOKEN[27]) and the renal inulin clearance (C_{In}). Ty = 95% tolerance range for Y/x[18]

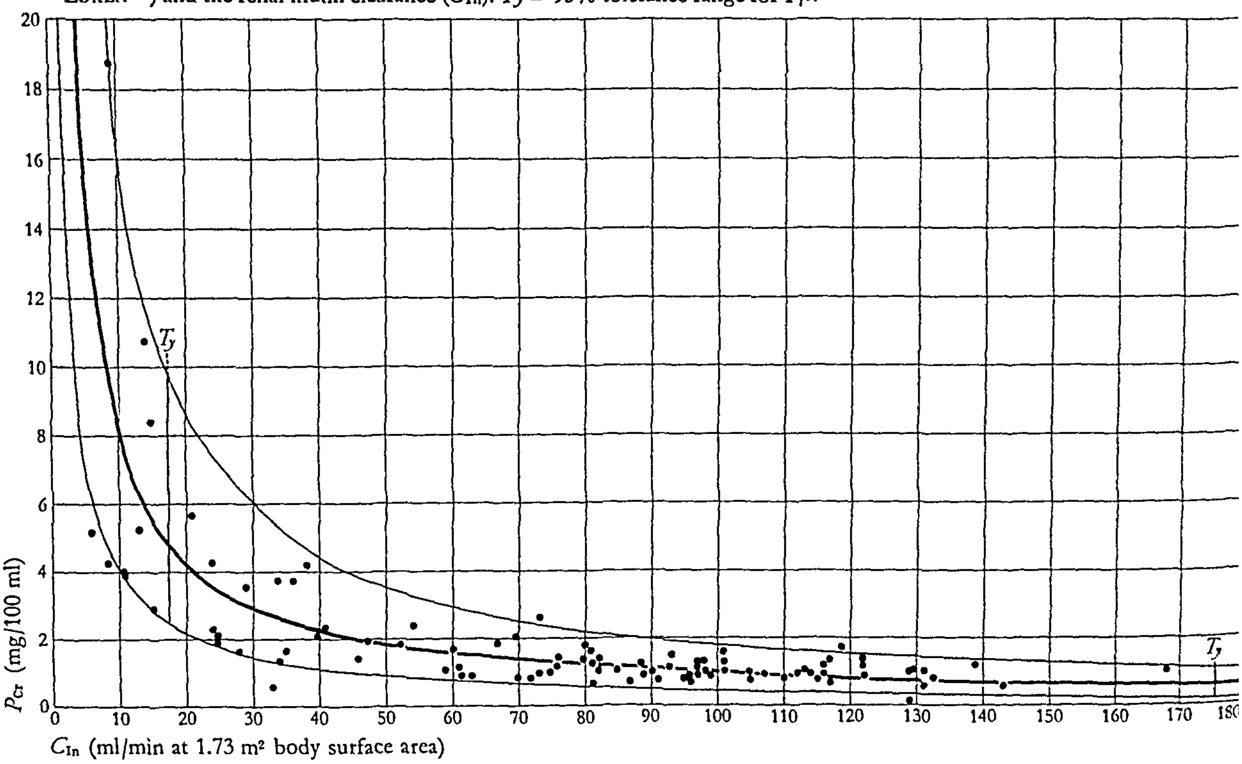
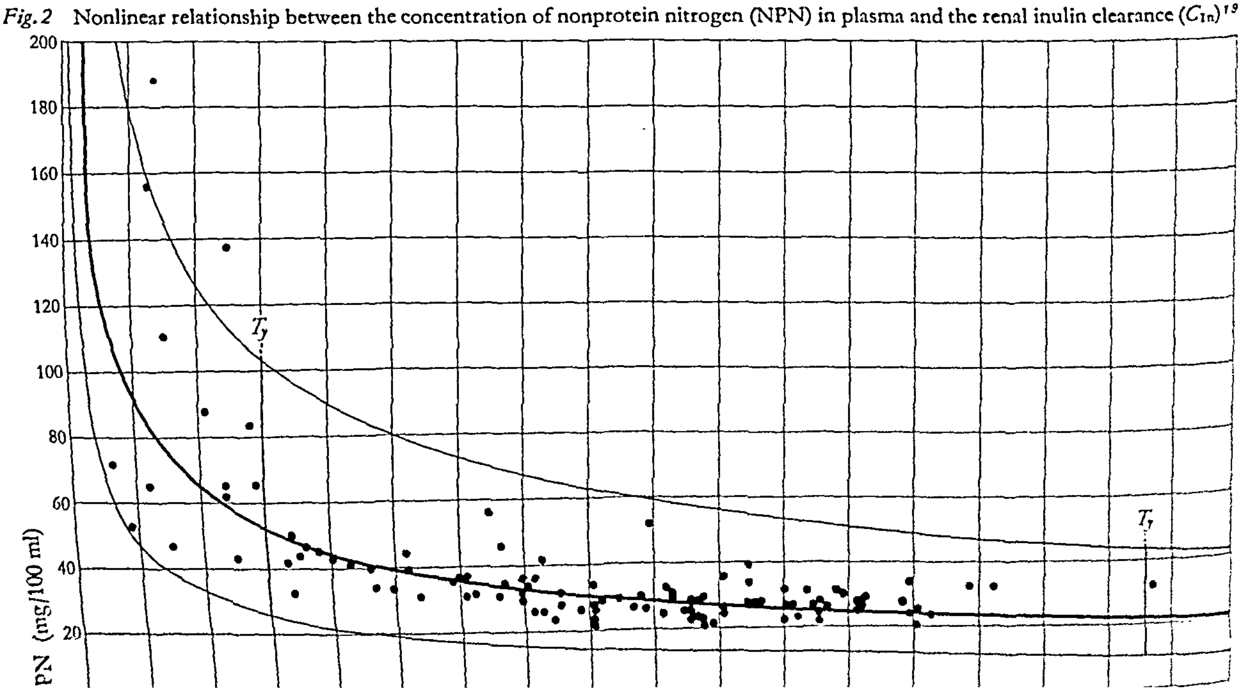
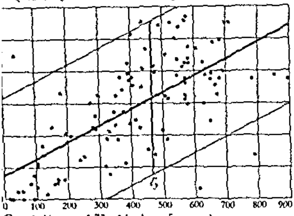


Fig. 2 Nonlinear relationship between the concentration of nonprotein nitrogen (NPN) in plasma and the renal inulin clearance (C_{In})[19]



(For references see page 536)

Linear relationship between the percentage excretion of phenolsulphonphthalein (PSP, 15-minute value after a single i v. injection of 6 mg) and the renal PAH clearance (C_{PAH}). Ty = 95% tolerance range for Y/x[24]



...librium of PSP in the body fluid compartments after a single ...ction, failure to take account of body weight in evaluating the ...lts, and the use of spontaneous urine samples[24]

...ution and concentration of urine

Tests of the diluting capacity of the kidneys are usually now ...pensed with If the organ can concentrate urine it must also be

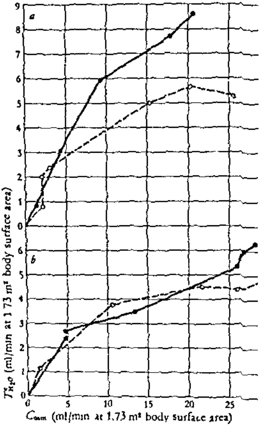
...antitative methods

When ADH (antidiuretic hormone) activity is at a maximum, the ...inary concentrating capacity is limited by two factors[28] (a) dur...g hydropenia and oliguria by the maximum value of the ratio ...tween the osmotic concentrations of the urine and plasma

Normal values

Maximum urinary osmolarity	900–1400 mosm/l[29-31]
	1027 ± 110 mosm/l[29]
	1067 (918–1230) mosm/l[32]
Maximum value of U_{osm}/P_{osm}	2.77 ± 0 36[33]
	3 63–4 65[34]
$Tm^c_{H_2O}$ (with i v infusion of hypertonic mannitol solution)	5 7 ± 2 0 ml/min[35]
$Tm^c_{H_2O}$ × 100/C_{In} (with i v. infusion of hypertonic mannitol solution)	5 1 ± 1 5[36]

Fig 4 Plots of $T^c_{H_2O}$ during saline diuresis (——) ar... diuresis (- - -) in (*a*) a healthy man and (*b*) ... essential hypertension[39]



a tendency to decrease (Fig 4). *In contrast to the vie...*

At maximum diuresis the *excess of osmotically free* ... pared to a hypothetical isosmotic urinary portion can be ... as the maximum free-water clearance ($Tm^e_{H_2O}$).

Normal values (1.73 m² body surface area)

$Tm^e_{H_2O}$ = maximum C_{H_2O} .... 17 ...
23 ...

Renal Function Values

(For references see page 536)

Fig. 5 Diagram for reading off values of $Tm^c_{H_2O}$ from those of U_{osm}/P_{osm} and the simultaneous urinary minute volume in osmotic diuresis[43]

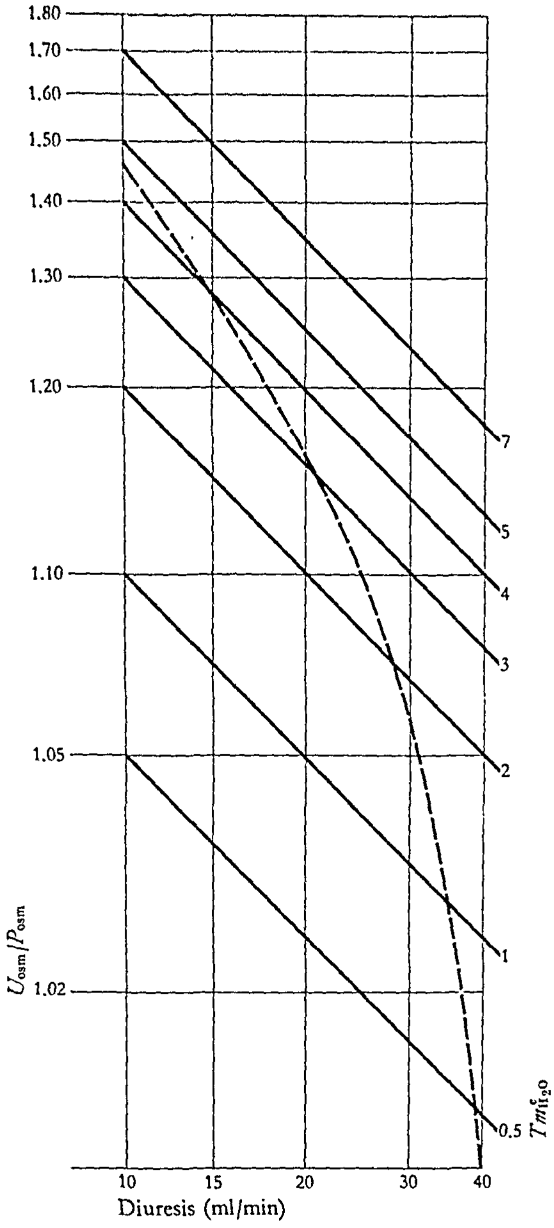
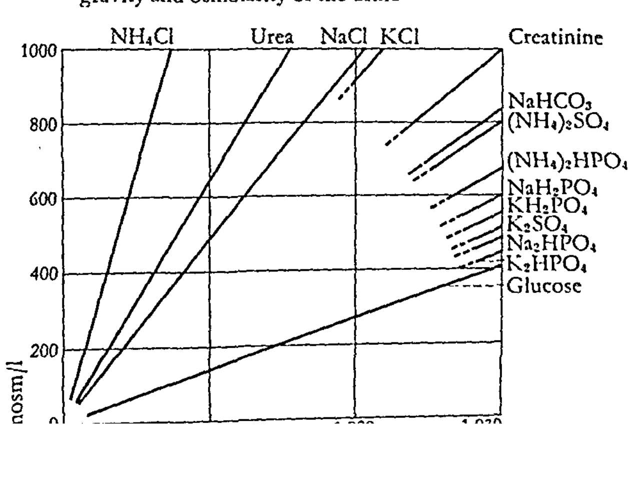


Fig. 6 Contributions of various urinary components to the specific gravity and osmolarity of the urine[49]



There are considerable discrepancies in the 'normal' values given in the literature for some of the parameters of renal concentrating capacity, a result of differences in the experimental methods. The concentrating capacity of the kidneys can be increased by means of a protein-rich diet[44]; it is decreased under conditions of inadequate dehydration[45] and in man (fluid deprivation test) is independent of the sodium chloride intake[46].

For persons between the ages of 24 and 72 years with healthy kidneys the age dependence of maximum urinary osmolality as found by a 24-hour fluid deprivation test is given by the formula[47]:

U_{osm} (in mosm/l) = 1134 − (4.1 × age in years)

Semiquantitative methods

While the underlying physiological process in the concentration of urine consists of the removal of osmotically-free water, the various electrolytes and nonelectrolytes present contribute in different degrees to the specific gravity and osmotic pressure. The determination of the *maximum specific gravity of urine* in the fluid deprivation test[48] must therefore be regarded as a semiquantitative test of renal function.

Glucose, phosphate and sulphate cause a high specific gravity of urine at fairly low osmotic concentrations[49], whereas chloride and urea exert a relatively high osmotic pressure for a given urinary specific gravity (Fig. 6). In persons with healthy kidneys the maximum urinary osmolarity reached in the fluid deprivation test is only loosely related to the maximum specific gravity[29]. The variance in the relationship between these two parameters increases in renal disease (Fig. 7)[30].

Normal specific gravity of urine (24-hour fluid deprivation test)	1.035 ± 4[27]
Lower limit of the normal (healthy kidney)	1.026[24, 27, 30]

The maximum urinary specific gravity falls from an average of 1.032 at 20 years to an average of 1.024 between 80 and 90 years[50].

Dependence of the 24-hour urinary volume on the amounts of solutes removed in the urine and the concentrating capacity of the kidneys

The amounts of solutes removed in the urine depend both on the dietary intake, particularly of proteins and salts, and on the calorie turnover of the body[51]. A mixed diet yields about 1200 mosm of urinary solutes per day[52], an amount reduced by fasting to about 800 mosm. In fasting subjects given 100 g glucose per day the urinary solutes fall to 400 mosm per day, while a diet low in protein and salt but rich in carbohydrates (with maintenance of the basal metabolic rate) results in a further reduction to 200 mosm per day. On the basis of a maximum urinary osmolarity of 1400 mosm/l the amounts of water required for the excretion of these amounts are 857, 571, 286 and 143 ml respectively. In isosthenuria (urinary osmolarity of 300 mosm/l) the renal elimination of 1200, 800, 400 and 200 mosm of urinary solutes requires respectively 4000, 2667, 1333 and 667 ml of water. The relationship between the renal water requirement and the urinary osmolarity for different daily amounts of solutes removed in the urine is shown in Figure 8[51].

Tubular transport functions

Clearance techniques enable an assessment to be made of the state of functioning of the active local transport mechanisms in the proximal tubular convolution. Both the tubular secretion of *p*-aminohippuric acid (PAH) and the reabsorption of glucose (G) from the tubular urine are limited by transport maxima (Tm)[1].

$$Tm_{PAH} = (U_{PAH} \times V) - (P_{PAH} \times C_{In} \times k)^{9} \quad (11)$$

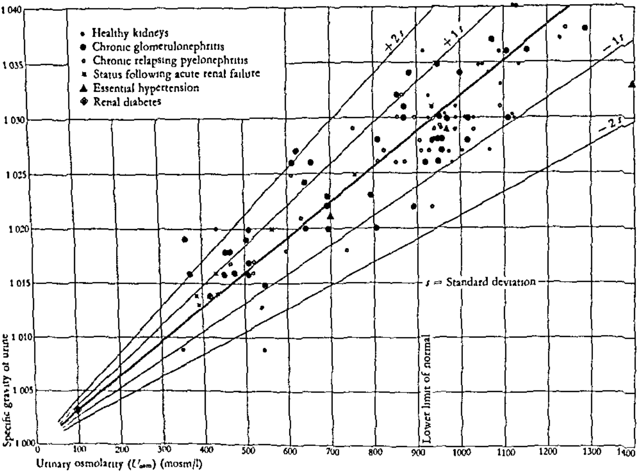
where U_{PAH} and P_{PAH} are the concentrations of PAH in urine and plasma respectively and k is a correction factor for the plasma PAH fraction that is protein-bound and not filtrable by the glomeruli. The normal value of k is 0.83.

$$Tm_G = (P_G \times C_{In}) - (U_G \times V) \quad (12)$$

Normal values (for 1.73 m² body surface area)

Tm_{PAH}	Men	79.8 ± 16.7 mg/min[2]
	Women	77.2 ± 10.8 mg/min[2]
Tm_G	Men	375 ± 79.7 mg/min[1,2]
	Women	303 ± 55.3 mg/min[1,2]

Fig 7 Relationship between the maximum urinary specific gravity (SU) achieved in the 18-hour fluid deprivation test and the corresponding osmolarity (U_{osm}) of the urine: (SU − 1.000) × 1000/U_{osm} = 0.0318 ± 0.0053[30]



These renal functions can be differentiated more precisely by relating Tm_{PAH} (as a measure of the functioning secretory renal tissue) and Tm_G (as a measure of the reabsorptive renal tissue) to C_{In} and C_{PAH} respectively. The ratios C_{In}/Tm_{PAH}, C_{PAH}/Tm_{PAH} and Tm_G/C_{In} are measures of glomerular activity, i.e., of the effective renal plasma flow per unit of the secretory or reabsorptive tissue.

Normal values	
C_{In}/Tm_{PAH}	1.54 ± 0.4 ml/mg[2]
C_{PAH}/Tm_{PAH}	8.28 ± 2.2 ml/mg[2]
Tm_G/C_{In}	2.41 ± 0.35 mg/ml[1]

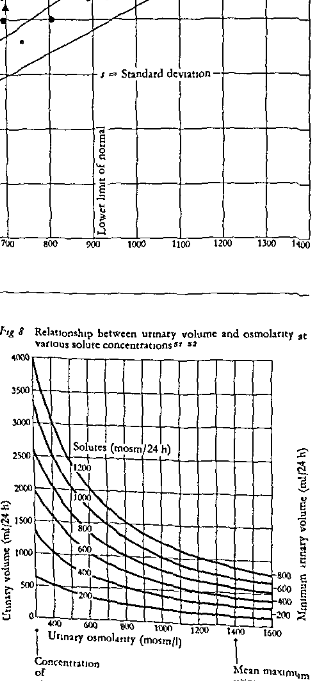
All these functions show age regression between the 20th and 90th years of life.

Tm_{PAH} = 120.6 − (0.865 × age in years)[15]
Tm_G = 432.8 − (2.604 × age in years)[50]
C_{In}/Tm_{PAH} = 1.382 − (0.00158 × age in years)[50]
C_{PAH}/Tm_{PAH} = 7.710 − (0.0278 × age in years)[50]

Excretion of acids and electrolytes

The *total acid excretion* (A_{H^+}) is made up of potentially ionizable hydrogen ions (titratable acidity, TA) and bound (nonionizable) hydrogen ions in the form of ammonium ions (NH_4^+).

Fig 8 Relationship between urinary volume and osmolarity at various solute concentrations[51,52]



Normal values (on a mixed diet)	
Total acid excretion (A_{H^+})	30–80 mEq/24 h[53]
Titratable acidity (A_{TA})	10–30 mEq/24 h[53]
NH_4^+ excretion ($A_{NH_4^+}$)	20–50 mEq/24 h[53]
$A_{NH_4^+}/A_{TA}$	1.0–2.5[53]
	1.28 ± 0.14[54]

The difference between the sum of the TA and NH_4^+ excretions and the bicarbonate excretion (HCO_3^-) is known as the *effective acid excretion* ($A_{H^+_{eff}}$).

$$A_{H^+_{eff}} = A_{H^+} - A_{HCO_3^-} = A_{TA} + A_{NH_4^+} - A_{HCO_3^-} \qquad (14)$$

In alkaline urine the effective acid excretion has a negative value since mainly bicarbonate ions are excreted.

The pH value of urine may vary between 4.6 and 8.2[2, 55].

An accurate assessment of the tubular treatment of an *electrolyte* from the excreted proportion of the amount filtered by the glomeruli is possible only when the substance concerned is freely filtrable and is exclusively reabsorbed in the tubules and not secreted. The only important electrolytes at present considered to fulfil this condition in man are sodium, chloride and bicarbonate.

Table 2 gives the mean values for the glomerular filtration and total excretion of some electrolytes in the 24-hour urine[24].

The *glomerular filtration rate* (GFR) of a completely filtrable electrolyte (E) is calculated as follows:

$$GFR_E \text{ (in mEq/min)} = k \times P_E \times C_{In} \qquad (15)$$

where P_E is the plasma concentration of the electrolyte (in mEq/l) and k a correction factor for the small differences between the concentrations in plasma and glomerular filtrate resulting from the Gibbs-Donnan equilibrium and the lowering of the water content of the plasma by the proteins.

The value of k is normally 1.02 for Cl^- and HCO_3^-[56], 0.96[57] for Na^+ and 0.92[57] for K^+.

For calculation of the amounts of partly plasma-protein-bound electrolytes filtered by the glomeruli it is important to know the filtrable part. This is dependent on the concentration and com[position] of the plasma proteins and on the pH value and other phy[sico]chemical conditions. 54% of the plasma calcium and 68% o[f] plasma magnesium are normally ultrafiltrable[58].

So-called 'normal' values for the clearance of electrolytes [have] little significance since they are very largely dependent on exoge[nous] factors.

Table 2 Amounts of solutes excreted and reabsorbed assuming a glomerular filtrate of 130 ml/min

	Amount filtered	Amount excreted in urine
Urea	46 g	20–35 g
Uric acid	7.2 g	0.1–2 g
Amino acids	50 g	0.5–1 g
Creatinine	1.2 g	1.2–1.5 g
Glucose	180 g	–
Albumin	36 g	–
Sodium	600 g	4–6 g
Chloride	640 g	6–9 g
Potassium	7.2 g	2.5–3.5 g
Bicarbonate	4900 mEq	1–2 mEq
Calcium	uncertain	0.01–0.3 g
Inorganic phosphate (as P)	5.6 g	1–5 g
Inorganic sulphate (as S)	2.9 g	1.4–3.3 g
Water	180 l	1.5 l

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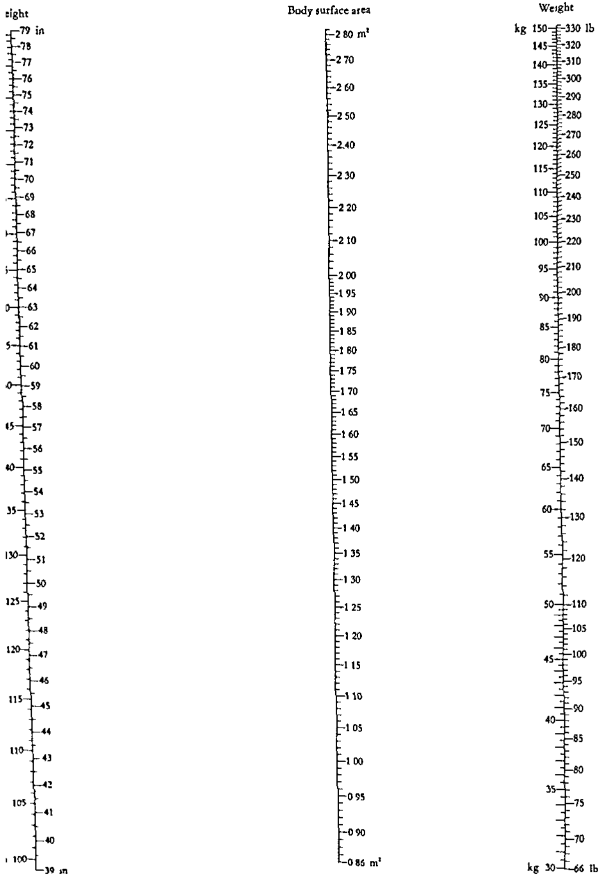
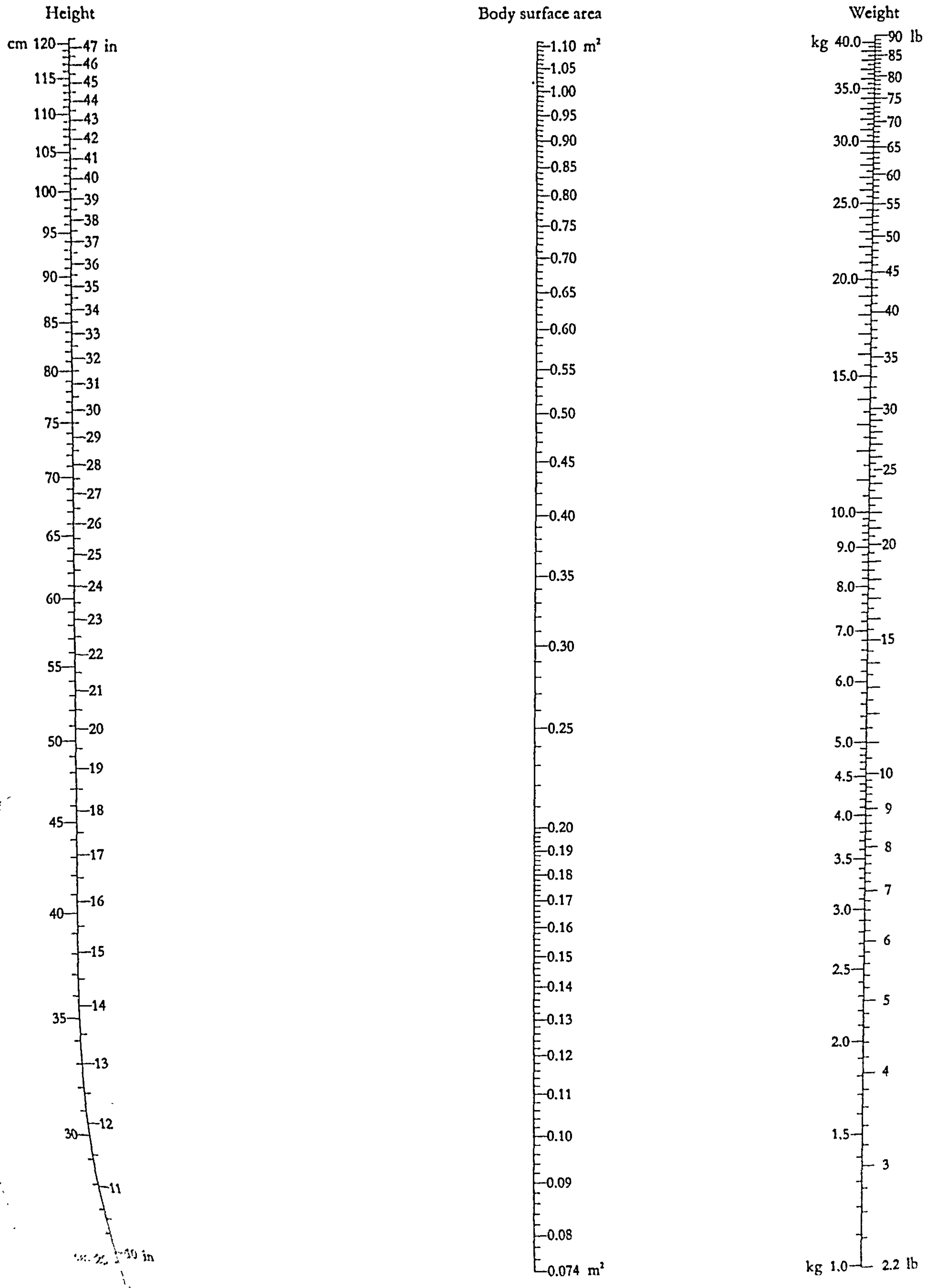
Nomogram for determination of body surface area from height and weight



om the formula of Du Bois and Du Bois, *Arch intern Med*, 17, 863 (1916) $S = W^{0.425} \times H^{0.725} \times 71.84$, or
: $S = \log W \times 0.425 + \log H \times 0.725 + 1.8564$ (S = body surface in cm², W = weight in kg, H = height in cm)

Nomogram for determination of body surface area from height and weight



[illegible] Du Bois and Du Bois, *Arch. intern. Med.*, 17, 863 (1916): $S = W^{0.425} \times H^{0.725} \times 71.84$, or [illegible] $H \times 0.725 + 1.8564$ (S = body surface in cm², W = weight in kg, H = height in cm)

:he basal metabolism (or basal metabolic rate, BMR) is the
ric requirement of the fasting body, physically and mentally at

Me

ntributions of various organs to the basal metabolism[1]

Organ	Weight (kg)	Proportion of body weight (%)	Oxygen consumption per kg (ml/min)	Oxygen consumption whole organ (ml/min)	Proportion of basal metabolism (%)
a) Liver.	1.5	2 1	44	66	26 4
b) Brain	1.4	2.0	33	46	18 3
(c) Heart	0 3	0 43	94	23	9 2
(d) Kidneys . ..	0 3	0 43	61	18	7.2
(a)–(d) together..	...	.	. .	153	61.1
(e) Skeletal muscle	27.8	39 7	2 3	64	25 6
Total (a)–(e) ...	.	.	.	217	86 7

The BMR is dependent on many factors[2, 3], particularly sex, eight and weight, bodily constitution, age and hormonal balance. 'aily and seasonal rhythms as well as climatic effects have also been bserved In women, slight variations occur during the course of e menstrual cycle[3, 4], and there is an increase of about 20% toards the end of pregnancy[5] Many standard values for the BMR ave been published, in common use are those of HARRIS and ENEDICT[6], BOOTHBY, BERKSON and DUNN[7], ROBERTSON and EID[8], and FLEISCH[9] Standard values for children have been ublished by SHOCK[10] and by LEWIS et al[11] The BMR of infants[12] and children[13] has been extensively investigated and that i the 50–90 year-old group has been the subject of a special tudy[14]

Standard values of the BMR are usually related to body surface rea (for the determination of body surface area see pages 537 and 38), but more recently suggestions have been made to use the fatree body mass (muscle mass or 'active tissue mass')[15], an accepted neasure of which is the urinary creatinine excretion[16] In infants he BMR is best related to body weight[17]

$$RQ = \frac{\dot V_{CO_2}}{\dot V_{O_2}}$$

Variation of RQ with age[18]

Newborn, first hours of life	0.90
first days of life	0.73
end of 1st week	0 82
Adults, postabsorptive (basal RQ)	0 82

The following formulae can be used for calculating the BMR ($\dot E$ = energy consumption in kilocalories per unit time, $\dot V_{O_2}$ = O_2 consumption in litres per unit time, $\dot V_{CO_2}$ = CO_2 production in litres per unit time, $\dot H_N$ = urinary nitrogen excretion in grammes per unit time):

$$\dot E = 4\,825\ \dot V_{O_2} \tag{1}$$

(when only O_2 consumption is measured)

$$\dot E = 3\,941\ \dot V_{O_2} + 1.106\ \dot V_{CO_2} \tag{2a}$$

$$\dot E = 3\,78\ \dot V_{O_2} + 1.16\ \dot V_{CO_2} \tag{2b}$$

(when O_2 consumption and CO_2 production are measured)

$$\dot E = 3\,941\ \dot V_{O_2} + 1\,106\ \dot V_{CO_2} - 2\,17\ \dot H_N \tag{3a}$$

$$\dot E = 3\,78\ \dot V_{O_2} + 1.16\ \dot V_{CO_2} - 2\,98\ \dot H_N \tag{3b}$$

(when protein breakdown is also determined)

Formula (1)[20] assumes a RQ of 0 82, the calorific values of LOEWY were used for formulae (2a) and (3a)[21], those of RUBNER for formulae (2b) and (3b)[22]

Calorific value, oxygen consumption and carbon dioxide production per gramme of protein, fat and carbohydrate burnt in the body and per gramme of nitrogen excreted in the urine[23]

	Oxygen consumed (ml/g)	Carbon dioxide produced (ml/g)	RQ	kcal/g from RUBNER	kcal/g from LOEWY	kcal/l Oxygen	kcal/l Carbon dioxide
Protein	966 3	773 9	0 801	4 10	4.316	4 485	5.579
Urinary N	5939 0	4757.0	0 801	25 63	26 54	4 485	5.579
Fat	2019 3	1427.3	0 707	9.3	9.461	4 686	6 629
Carbohydrate	828 8	828 8	1 000	4 1	4 182	5 047	5.047

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Standard BMR values

kcal/m²/h

Age in years	Men: Standard of *Handbook of Biological Data*[1] Mean	Men: Standard of *Handbook of Biological Data*[1] 95% range	Men: Standard of Fleisch[2] Mean	Women: Standard of *Handbook of Biological Data*[1] Mean	Women: Standard of *Handbook of Biological Data*[1] 95% range	Women: Standard of Fleisch[2] Mean
1	–	–	53.0	–	–	53.0
2	–	–	52.4	–	–	52.4
3	60.1	51.8–68.3	51.3	54.5	47.0–62.0	51.2
4	57.9	49.9–65.9	50.3	53.9	46.5–61.3	49.8
5	56.3	48.5–64.1	49.3	53.0	45.7–60.3	48.4
6	54.0	46.5–61.5	48.3	51.2	44.1–58.3	47.0
7	52.3	45.1–59.5	47.3	49.7	42.8–56.6	45.4
8	50.8	43.8–57.8	46.3	48.0	41.4–54.6	43.8
9	49.5	42.7–56.3	45.2	46.2	39.8–52.6	42.8
10	47.7	41.1–54.3	44.0	44.9	38.7–51.1	42.5
11	46.5	40.1–52.9	43.0	44.1	38.0–50.2	42.0
12	45.3	39.0–51.6	42.5	42.0	36.2–47.8	41.3
13	44.5	38.4–50.6	42.3	40.5	34.9–46.1	40.3
14	43.8	37.8–49.8	42.1	39.2	33.8–44.6	39.2
15	43.7	37.7–49.7	41.8	38.3	33.0–43.6	37.9
16	42.9	37.0–48.8	41.4	37.7	32.5–42.9	36.9
17	41.9	36.1–47.7	40.8	36.2	31.2–41.2	36.3
18	40.5	34.9–46.1	40.0	35.7	30.8–40.6	35.9
19	40.1	34.6–45.6	39.2	35.4	30.5–40.3	35.5
20	39.8	34.3–45.3	38.6	35.3	30.4–40.2	35.3
21	39.4	34.0–44.8	–	35.2	30.3–40.1	–
22	39.2	33.8–44.6	–	35.2	30.3–40.1	–
23	39.0	33.6–44.4	–	35.2	30.3–40.1	–
24	38.7	33.4–44.0	–	35.1	30.3–39.9	–
25	38.4	33.1–43.7	37.5	35.1	30.3–39.9	35.2
26	38.2	32.9–43.5	–	35.0	30.2–39.8	–
27	38.0	32.8–43.2	–	35.0	30.2–39.8	–
28	37.8	32.6–43.0	–	35.0	30.2–39.8	–
29	37.7	32.5–42.9	–	35.0	30.2–39.8	–
30	37.6	32.4–42.8	36.8	35.0	30.2–39.8	35.1
31	37.4	32.2–42.6	–	35.0	30.2–39.8	–
32	37.2	32.1–42.3	–	34.9	30.1–39.7	–
33	37.1	32.0–42.2	–	34.9	30.1–39.7	–
34	37.0	31.9–42.1	–	34.9	30.1–39.7	–
35	36.9	31.8–42.0	36.5	34.8	30.0–39.6	35.0
36	36.8	31.7–41.9	–	34.7	29.9–39.5	–
37	36.7	31.6–41.8	–	34.6	29.8–39.4	–
38	36.7	31.6–41.8	–	34.5	29.7–39.3	–
39	36.6	31.5–41.7	–	34.4	29.7–39.1	–
40	36.5	31.5–41.5	36.3	34.3	29.6–39.0	34.9
45	36.3	31.3–41.3	36.2	33.9	29.2–38.6	34.5
50	36.0	31.0–40.0	35.8	33.4	28.8–38.0	33.9
55	35.4	30.5–40.3	35.4	32.9	28.4–37.4	33.3
60	34.8	30.0–39.6	34.9	32.4	27.9–36.9	32.7
65	34.0	29.3–38.7	34.4	31.8	27.4–36.2	32.2
70	33.1	28.5–37.7	33.8	31.3	27.0–35.6	31.7
75 and over	31.8	27.4–36.2	33.2	31.1	26.8–35.4	31.3

kJ/m²/h*

Age in years	Men: Standard of *Handbook of Biological Data*[1] Mean	Men: Standard of *Handbook of Biological Data*[1] 95% range	Men: Standard of Fleisch[2] Mean	Women: Standard of *Handbook of Biological Data*[1] Mean	Women: Standard of *Handbook of Biological Data*[1] 95% range	Women: Standard of Fleisch[2] Mean
1	–	–	222	–	–	222
2	–	–	219	–	–	219
3	252	217–286	215	228	197–260	214
4	242	209–276	211	226	195–257	208
5	236	203–268	206	222	191–252	203
6	226	195–257	202	214	185–244	197
7	219	189–249	198	208	179–237	190
8	213	183–242	194	201	173–229	183
9	207	179–236	189	193	167–220	179
10	200	172–227	184	188	162–214	178
11	195	168–221	180	185	159–210	176
12	190	163–216	178	176	152–200	173
13	186	161–212	177	170	146–193	169
14	183	158–208	176	164	141–187	164
15	182	158–208	175	160	138–182	159
16	180	155–204	173	158	136–180	154
17	175	151–200	171	152	131–172	152
18	170	146–193	167	149	129–170	150
19	168	145–191	164	148	128–169	149
20	167	144–190	162	148	127–168	148
21	165	142–188	–	147	127–168	–
22	164	141–187	–	147	127–168	–
23	163	141–186	–	147	127–168	–
24	162	140–184	–	147	127–167	–
25	161	139–183	157	147	127–167	147
26	160	138–182	–	146	126–167	–
27	159	137–181	–	146	126–167	–
28	158	136–180	–	146	126–167	–
29	158	136–180	–	146	126–167	–
30	157	136–179	154	146	126–167	147
31	157	135–178	–	146	126–167	–
32	156	134–177	–	146	126–166	–
33	155	134–177	–	146	126–166	–
34	155	134–176	–	146	126–166	–
35	154	133–176	153	146	126–166	146
36	154	133–175	–	145	125–165	–
37	154	132–175	–	145	125–165	–
38	154	132–175	–	144	124–164	–
39	153	132–175	–	144	124–164	–
40	153	132–174	152	144	124–163	146
45	152	131–173	152	142	122–162	144
50	151	130–167	150	140	121–159	142
55	148	128–169	148	138	119–157	139
60	146	126–166	146	136	117–154	137
65	142	123–162	144	133	115–152	135
70	139	119–158	141	131	113–149	133
75 and over	133	115–152	139	130	112–148	131

* The values in kJ have been calculated by using the relationship 1 $kcal_{IS}$ = 4.1855 kJ (see page 213).

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Respiration

(For references see page 546)

Symbols used in respiratory physiology[1]

1. *Gas phase*

(a) Primary symbols (italic capitals)
(A point over a symbol indicates a time derivative, a bar a mean value)

- V Gas volume
- $\dot{V}$ Gas volume per unit time
- P Gas pressure (partial pressure)
- $\bar{P}$ Mean gas pressure
- F Fractional concentration in dry gas phase
- f Respiratory frequency (breaths per unit time)
- D Diffusing capacity

(b) Secondary symbols (small italic capitals) and abbreviations (small upright capitals)

- I Inspired gas
- E Expired gas
- A Alveolar gas
- D Dead-space gas
- T Tidal gas
- B Barometric pressure
- STPD Standard temperature and pressure, dry (gas at 760 mm Hg, dry)
- BTPS Body temperature and pressure, saturated with vapour (gas at 37 °C, measured barometric pressur urated)
- ATPS Ambient temperature and pressure, saturated (ambient temperature and pressure, saturated with vapour)

2. *Blood phase*

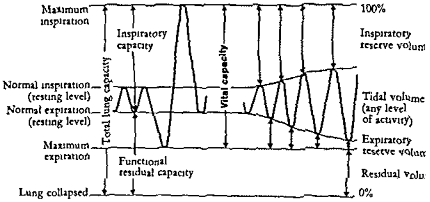
(a) Primary symbols (italic capitals)

- Q Blood volume
- $\dot{Q}$ Blood volume per unit time
- S O_2 or CO_2 saturation of haemoglobin (as percent O_2 or CO_2 capacity)

(b) Secondary symbols (italic small letters)

- *a* Arterial blood
- *v* Venous blood
- *c* Capillary blood

Respiratory variable	Definition	Unit	Remarks, normal values
Lung volumes and capacities	*Subdivisions of the lung volume*[1]		



Respiratory variable	Definition	Unit	Remarks, normal values
	The subdivisions on the right apply to all levels of respiratory effort and do not overlap. The capacities on the left include two or more of the primary subdivisions		All volumes to be corrected to BTPS (also page 269). Measurements are usu made on the recumbent patient; rat *higher values* are obtained if the patien sitting or standing[2]
Tidal volume (V_T)	The volume of air inspired and expired at each breath	l	For normal values see Table 1, page 55
Inspiratory reserve volume (IRV)	The maximum volume of air that can be additionally inspired after a normal inspiration	l	
Expiratory reserve volume (ERV)	The maximum volume of air that can be additional expired after a normal expiration	l	For normal values see Table 2, page 55

Respiration

(For references see page 546)

Respiratory variable	Definition	Unit	Remarks, normal values
Residual volume (RV)	The volume of air remaining in the lungs after a maximum expiration	l	For normal values see Tables 2, 3 and 5, pages 550–551
Total lung capacity (TLC)	The volume of air contained in the lungs after a maximum inspiration	l	For normal values see Table 2, page 550, and Table 5, page 551. For determination in children see Figure 1, page 547. The total lung capacity can be calculated from the normal vital capacity as follows[3]: $\left.\begin{array}{l}\text{15–34 years } 0.8\\ \text{35–49 years } 0.75\\ >50 \text{ years } 0.65\end{array}\right\} \times$ vital capacity
Vital capacity (VC)	The maximum volume of air that can be forcibly inspired after a maximum expiration (inspiratory vital capacity) or that can be forcibly expired after a maximum inspiration (expiratory vital capacity)	l	It is better to measure the inspiratory VC since this is reproducible even in diseased persons, whereas the expiratory VC may fluctuate as a result of the check-valve mechanism. For normal values see Table 2, page 550, and Tables 3–5, page 551. For measurement in ambulant or bedded patients with healthy lungs see Figures 3 and 4, page 547. The 'crying' VC of the newborn is about 0.14 l[4]
Inspiratory capacity (IC)	The maximum volume of air that can be inspired from the resting expiratory level	l	For normal values see Table 2, page 550
Functional residual capacity (FRC)	The volume of air in the lungs at the resting expiratory level	l	For normal values see Table 2, page 550. For determination in children see Figure 2, page 547. The FRC of the newborn is about 70 ml[4]
Ventilation			
Minute ventilation ($\dot{V}_T$)	The volume of air inspired or expired in one minute	l min^{-1}	Since the respiratory quotient in normal breathing at rest is less than 1, the inspiratory minute ventilation differs from the expiratory minute ventilation. The amount of the minute volume is a function mainly of the energy consumption of the body, the dead-space ventilation and the respiratory frequency, and is thus subject to large individual variations. For calculation of the normal value see Rossier et al.[5]. For normal measured values see Table 1, page 550
Alveolar ventilation ($\dot{V}_A$)	The volume of air entering the alveoli per minute, or the amount of alveolar air expired per minute	l min^{-1}	In a young man weighing 70 kg with an O_2 intake of 250 ml/min the alveolar ventilation must be at least 4.3 l/min if arterialization is to be complete[3]. The alveolar ventilation is calculated by means of Bohr's alveolar equation. The normal value is affected by postural changes and under resting conditions is 70–80%, under heavy loading about 85%, of the total ventilation; the remainder is the dead-space ventilation, or functional dead space[5,6]

Respiration

(For references see page 546)

Respiratory variable	Definition	Unit	Remarks, normal values
iratory time quotient	Ratio of the time of expiration to the time of inspiration		For normal values see Table 1, page 550
ing time	The time required for stabilization of the gas concentration in the lung-spirometer system		[illegible] circuit method. Mixing is normally complete after 2-3 min. For helium methods see Briscoe[7]
ts of ventilatory function			
ximum voluntary ventilation (*VV*), *maximum breathing capacity* (*BC*)	The maximum minute ventilation attainable by voluntary hyperventilation	$l\,min^{-1}$	Calculated from the value measured over [illegible] tory volume × 37, or normal vital capacity × 30 For normal values in adults see Figure 6, page 548. For values used in the evaluation of permanent impairment see the literature[10]
rced expiratory volume (FEV_t)	The volume of air expired per unit time during forced expiration following full inspiration	l	[illegible] For normal values in the UK and USA see the literature[10,11]
ercentage forced expiratory volume	The forced expiratory volume expressed as percentage of the vital capacity $100\,FEV_t/VC$	%	For normal values see Table 5, page 551, and Figure 8, page 549
Maximum expiratory flow rate (MEFR), *peak flow rate*	The flow rate at a particular point during forced expiration	$l\,s^{-1}$	[illegible] 13, page 550
Maximum inspiratory flow rate (MIFR)	The flow rate at a particular point during forced inspiration	$l\,s^{-1}$	
Maximum mid-expiratory flow (MMF)	The flow rate during the middle half of a forced expiration	$l\,s^{-1}$	For normal values in adults see Figure 9, page 549
Pulmonary circulation			
Intravascular pressure	The ratio of the blood pressure in any part of the blood vessel to the atmospheric pressure	mm Hg	For normal values see page 553

Respiration

(For references see page 546)

Respiratory variable	Definition	Unit	Remarks, normal values
espiratory time quotient	*Ratio of the time of expiration to* the time of inspiration		*For normal values see Table 1, page 550*
Mixing time	The time required for stabilization of the gas concentration in the lung-spirometer system		[illegible] see BRISCOE[7]

Tests of ventilatory function

Respiratory variable	Definition	Unit	Remarks, normal values
Maximum voluntary ventilation (MVV), *maximum breathing capacity* (MBC)	The maximum minute ventilation attainable by voluntary hyperventilation	$l\ min^{-1}$	Calculated from the value measured over 10–20 s For determination from age and respiratory frequency see Figure 5, page 548 Normal value at a respiratory frequency of 50/min[8,9], one-second forced expiratory volume × 37, or normal vital capacity × 30 For normal values in adults see Figure 6, page 548. For values used in the evaluation of permanent impairment see the literature[10]
Forced expiratory volume (FEV_t)	The volume of air expired per unit time during forced expiration following full inspiration	l	[illegible] For normal values in the UK and USA see the literature[10,11]
Percentage forced expiratory volume	The forced expiratory volume expressed as percentage of the vital capacity $100\ FEV_t/VC$	%	For normal values see Table 5, page 551, and Figure 8, page 549
Maximum expiratory flow rate (MEFR), *peak flow rate*	The flow rate at a particular point during forced expiration	$l\ s^{-1}$	[illegible] 13, page 550
Maximum inspiratory flow rate (MIFR)	The flow rate at a particular point during forced inspiration	$l\ s^{-1}$	
Maximum mid-expiratory flow (MMF)	The flow rate during the middle half of a forced expiration	$l\ s^{-1}$	For normal values in adults see Figure 9, page 549

Pulmonary circulation

Respiratory variable	Definition	Unit	Remarks, normal values
Intravascular pressure	The ratio of the blood pressure in any part of the blood vessel to the atmospheric pressure	mm Hg	For normal values see page 553

Respiration

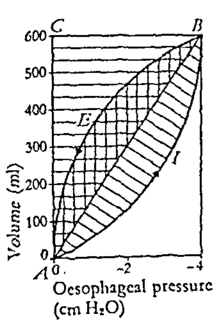
(For references see page 546)

Respiratory variable	Definition	Unit	Remarks, normal values
Transmural pressure	The difference between the blood pressure in the vessel and the external pressure on the vessel	mm Hg	The pressure acting externally on th monary arteries and veins is equal t intrathoracic pressure
Driving pressure	The pressure difference between the two ends of any section of a blood vessel	mm Hg	
Vascular resistance	Ratio of the driving pressure in the pulmonary circulation to the minute volume	dyn s cm^{-5}	
Minute volume	The volume of blood passing through the lungs in one minute	l min^{-1}	Obtained by using FICK's principle, acc ing to which the minute volume is equ the ratio $\frac{O_2 \text{ intake (ml/min)}}{\text{arteriovenous } O_2 \text{ difference (ml/l)}}$ In resting adults the blood flow througl lungs is about 5 l/min
Intrapulmonary blood volume	The volume of blood contained between the origin of the pulmonary artery and the junction of the pulmonary veins with the left atrium	l	Normal value in adults about 900 ml. volume of blood contained in the pul nary capillaries in resting adults is 75- ml[3]. For normal values in children BUCCI[12]
Ventilation/perfusion ratio ($\dot{V}_A/\dot{Q}$)	Ratio of the alveolar ventilation to the blood flow in the capillaries (perfusion)		In resting adults the alveolar ventilatio about 4 l/min and the blood flow ab 5 l/min, so that the ventilation/perfus ratio is about 0.8
Intrapulmonary shunt volume	Proportion of venous blood in the blood flowing through the aorta	vol%	Physiologically, the venous blood pre derives from the bronchial venous bl flowing into the pulmonary veins, fr intrapulmonary arteriovenous shunts, to a lesser extent from coronary ven blood entering via the veins of THEBES and via communications between the po and pulmonary veins and the mediasti and pulmonary veins. Normal value young adults at rest 2 (0–4)%[13]
Blood gases and diffusion	The pressures given are partial pressures (the partial pressure of a component of a gas mixture is the pressure it would exert if it alone occupied the whole volume of the mixture). The pressure of an (ideal) gas mixture is equal to the sum of the partial pressures of its components		Most types of gas analysis apparatus gi so-called dry percentages of the gases, a expressed as fractions F of the dry gas m ture. The pressure P of a component gas mm Hg) in the original mixture is given $P_{gas} = F_{gas}\,(B - P_{H_2O})$, where B = barometric pressure (mm H; P_{H_2O} = 47 mm Hg at 37 °C
Alveolar O_2 pressure ($P_{A_{O_2}}$)		mm Hg	Adults[9]: 100 (95–105) mm Hg
Alveolar CO_2 pressure ($P_{A_{CO_2}}$)		mm Hg	Adults[9]: 40 (38–42) mm Hg
Arterial O_2 saturation ($S_{a_{O_2}}$)		%	Adults[9]: 97 (95–99)%. See also page 57(
Arterial O_2 pressure ($P_{a_{O_2}}$)		mm Hg	Adults[9]: 80–100 mm Hg. See also page 57

Respiratory variable	Definition	Unit	Remarks, normal values
rterial CO_2 pressure (Pa_{CO_2})		mm Hg	Adults[9]: 40 (38–42) mm Hg. See also page 570
rterial pH value			Adults[9], 7 4 (7.36–7.44) See also page 560
iffusing capacity (D)	The rate at which a gas passes from the alveoli into the blood at a partial-pressure difference of 1 mm Hg	ml min⁻¹ mm Hg⁻¹	Measured by using CO or O_2 The diffusing capacity is affected by constitution, age lung volume, metabolic state and posture. For normal values in the lung itself (D_L see Table 7, page 552. The value for CO is [illegible] $$\frac{1}{D_L} = \frac{1}{D_M} + \frac{1}{\vartheta V_c}$$ where ϑ is a velocity constant (dependent on P_{CO_2}), V_c the volume of blood in the capillaries
Difference between alveolar and arterial partial pressure of O_2	$P_{AO_2} - P_{aO_2}$	mm Hg	[illegible] constitutes the arterial blood), (2) the non-uniformity of the ventilation-perfusion process in the different parts of the lung (even in healthy persons ventilation is in excess of perfusion or vice versa in some alveoli), and (3) the fall in partial pressure due to perfusion (of little consequence in healthy persons under normal conditions) The difficulty of calculating the last factor precisely is the reason for the wide fluctuations in published data on the diffusing capacity of the lungs for O_2
Respiratory mechanics			
Compliance (C)	The expansibility of the lungs and/or thorax expressed as the volume change per unit pressure change	l cm H_2O^{-1}	Normal values in *young men*[3] Compliance of the lungs (C_L) about 0 2 l cm H_2O^{-1} Compliance of the thorax (C_T) about 0 2 l cm H_2O^{-1} Compliance of the lungs + thorax (C_{L+T}) about 0 1 l cm H_2O^{-1} where $\frac{1}{C_{L+T}} = \frac{1}{C_L} + \frac{1}{C_T}$ Compliance of the lungs in the *newborn*[4] 5 ml cm H_2O^{-1} Compliance of the lungs in *children* see Figure 11, page 549 Compliance of the lungs in *adults*; see Table 9, page 552
Specific compliance	The ratio of compliance to functional residual capacity		Per litre of functional residual capacity[5] Adults 0 05–0 06 l cm H_2O^{-1} Newborn 0 065 l cm H_2O^{-1}
Elastance	Reciprocal of the compliance	cm H_2O l⁻¹	A measure of the elastic resistance of the lungs and thorax

Respiratory variable	Definition	Unit	Remarks, normal values
Nonelastic (viscous) resistances	Expressed as the pressure difference corresponding to unit ventilation	cm H_2O s l^{-1}	
Airway resistance	Resistance to flow in the airways		Can be measured by means of the bod[y] plethysmograph, usually with rapid supe[r]ficial breathing (frequency 200/min). Fo[r] normal values see Table 8, page 552. Fo[r] values at normal respiratory frequency se[e] JAEGER and OTIS[14]
Pulmonary tissue resistance	Frictional and deformational resistance of the pulmonary tissue		Obtained as the difference between the pulmonary total and airway resistances. For normal values see Table 8, page 552
Total pulmonary resistance	Airway resistance plus tissue resistance		Determined by measuring the intrathoraci[c] or oesophageal pressure. In healthy younger subjects about 20% is tissue resistanc[e] and about 80% airway resistance. For normal values in children see Figure 12, page 549, in adults Table 8, page 552
Thoracic tissue resistance	Deformational resistance of the thoracic tissue		Obtained approximately as the difference between the total respiratory and total pulmonary resistances
Total (nonelastic) respiratory resistance	Total pulmonary resistance plus thoracic tissue resistance		Can be measured approximately by means of a pneumotachograph. Exact values can be obtained only by using a respirator ('iron lung') with complete relaxation of the muscles involved in respiration
Conductance	Reciprocal of the nonelastic resistance	l s^{-1} cm H_2O^{-1}	
Work of breathing (A)	The work required to overcome the elastic and nonelastic resistances of the lungs and thorax and the airway resistance: A = force × distance = pressure × volume	m kg or l atm	The total work of breathing can be precisely determined only by having the subject breathe passively in a respirator and measuring the pressures required for various minute ventilations. For a tidal volume of 500 ml and respiratory frequency of 15/min this method gives a total work of breathing of 0.315 kg m min^{-1} [15]. By ignoring the work required to overcome the thoracic tissue resistance, the work of breathing can be obtained from the respiratory loop (see the adjacent diagram). It is the sum of the products of the forces (measurable as pressures in the oesophagus) and corresponding tidal volumes. The respiratory loop can be calculated from the pneumotachogram and pressure curve or registered by means of a cathode-ray oscillograph or other directly recording instrument. For normal values of the components of the work of breathing for a single breath see Table 10, page 552

Volume–pressure diagram for a single breath (respiratory loop)[16]



Area *AIBC* Total work done against the elastic and nonelastic resistances of the pulmonary tissue and the airway resistance

Area *AIB* Work done against the nonelastic resistance of the pulmonary tissue and the airway resistance during inspiration

Area *ABC* Work done against the elastic resistance of the pulmonary tissue during inspiration

Area *BEA* Work done against the nonelastic resistance of the pulmonary tissue and the airway resistance during expiration. Expiration does not require active work but takes place passively through the elastic contraction of the lung expanded during inspiration

References

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14 JAEGER and OTIS, *J. appl. Physiol.*, 19, 813 (1964).
15 OTIS et al., *J. appl. Physiol.*, 2, 592 (1950); OTIS, A. B., *Physiol. Rev.*, 34, 449 (1954).
16 HAMM et al., *Z. klin. Med.*, 157, 133 (1962).

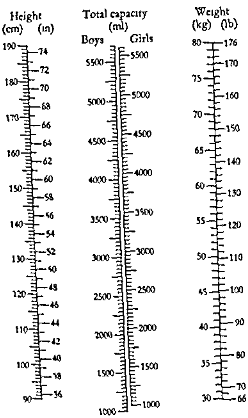


Fig. 1. Determination of total lung capacity in children (from LYONS and TANNER, *J appl. Physiol.*, 17, 601 [1962])

Fig. 2 Determination of functional residual capacity in children (from LYONS and TANNER, *J appl Physiol.*, 17, 601 [1962])

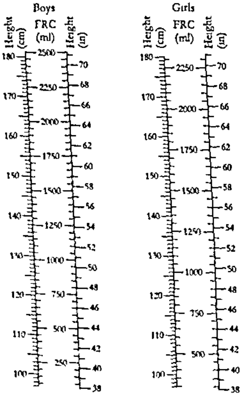


Fig. 3 Determination of vital capacity in healthy adults (from MILLER et al., *J. appl Physiol.*, 14, 157 [1959])

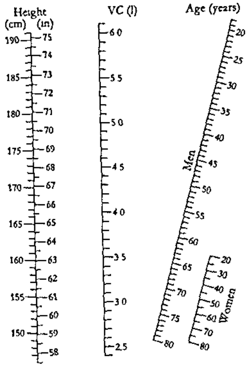
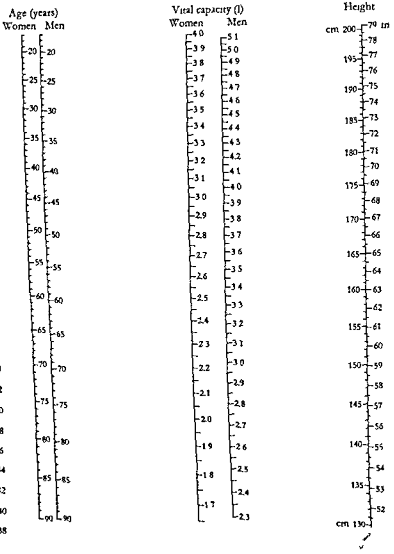


Fig 4 Determination of vital capacity in recumbent healthy adults (from BALDWIN et al., *Medicine [Baltimore]*, 27, 243 [1948])



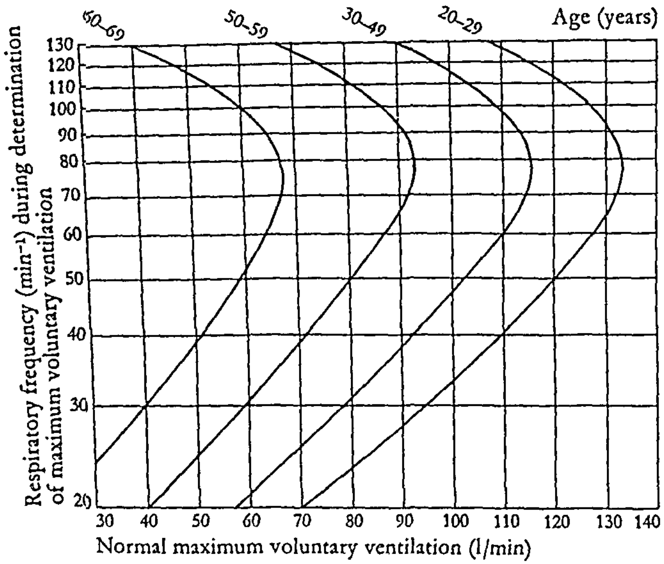
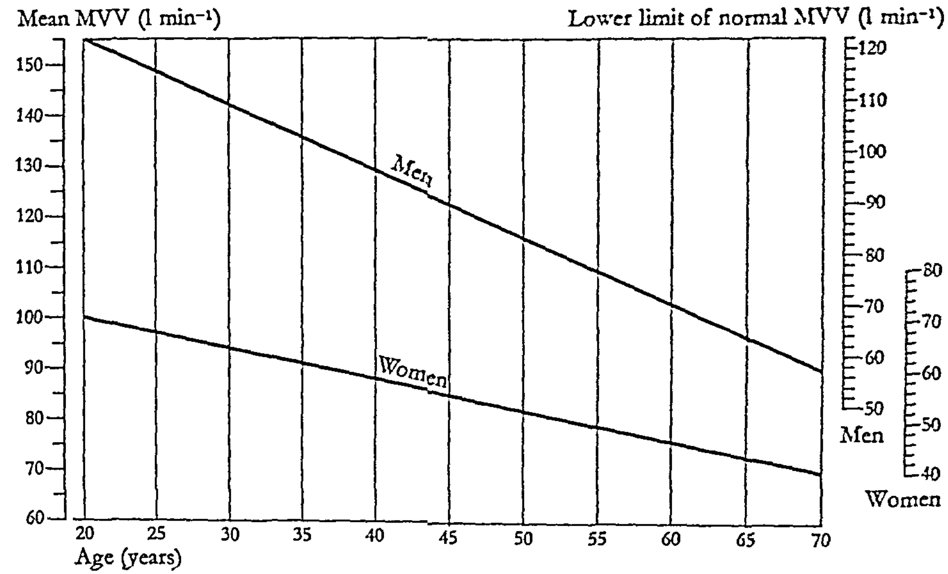


Fig. 5. Determination of maximum voluntary ventilation as a function of respiratory frequency (from Fruhmann and Ziegler, *Z. klin. Med.*, **157**, 586 [1963])

Fig. 6. Determination of maximum voluntary ventilation (MVV) in adults (respiratory frequency 40/min) (from Birath et al., *Acta med. scand.*, **173**, 193 [1963])



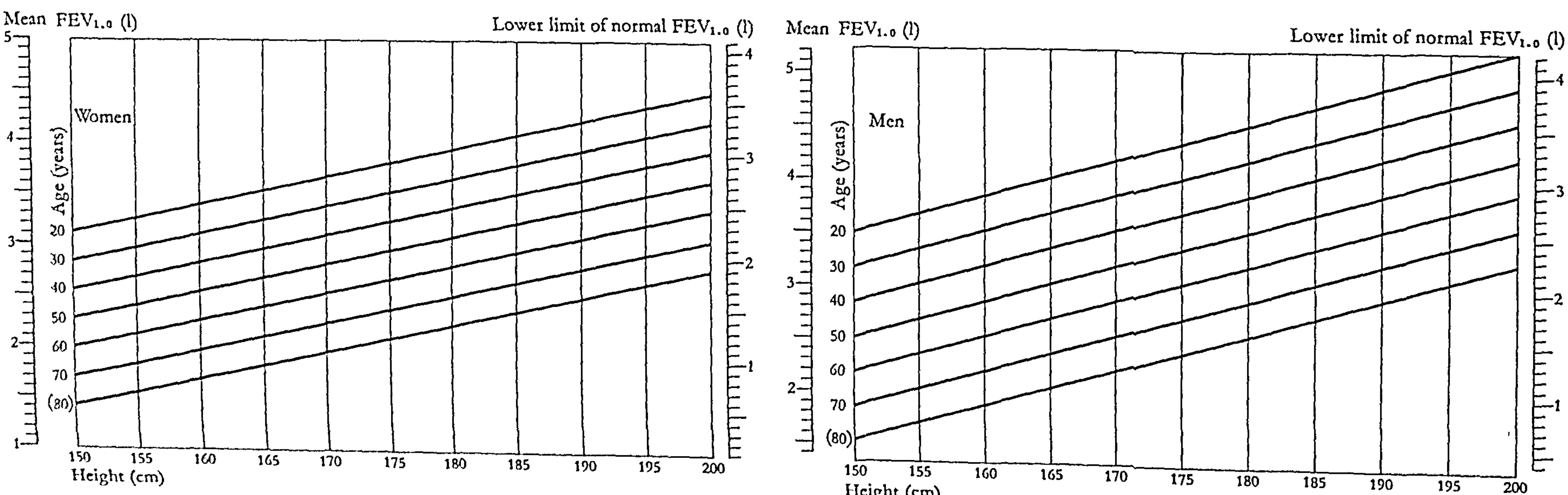


Fig. 7. Determination of forced expiratory volume ($FEV_{1.0}$) in adults (from Berglund et al., *Acta med. scand.*, **173**, 185 [1963])

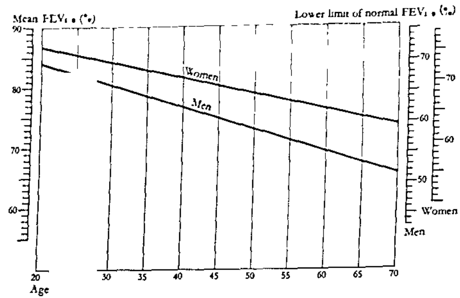


Fig. 8 De n of percentage forced expiratory volume ($FEV_{1\,s}$) in adults (from BERGLUND et al., *Acta med scand*, 173, 185 [1963])

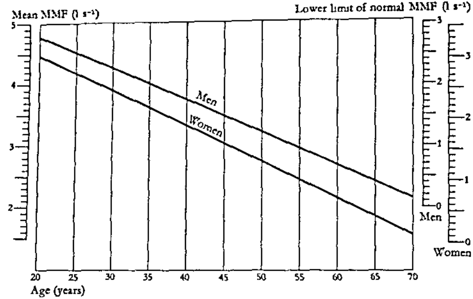


Fig 9 Determination of maximum mid-expiratory flow (MMF) in adults (from BIRATH et al, *Acta med scand*, 173, 193 [1963])

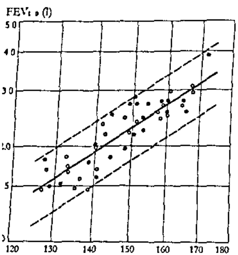


Fig 10

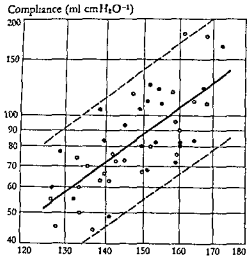


Fig. 11

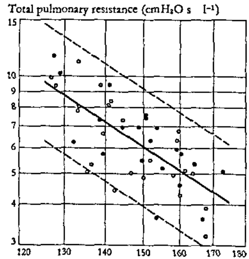


Fig 12

Figs. 10–12. Determination of forced expiratory volume ($FEV_{1\,s}$), compliance and total pulmonary resistance in children (from ENGSTRÖM et al., *Acta paediat. [Uppsala]*, 51, 68 [1962])

- ● Boys
- ○ Girls
- —— Regression line
- ----- 95% confidence limits

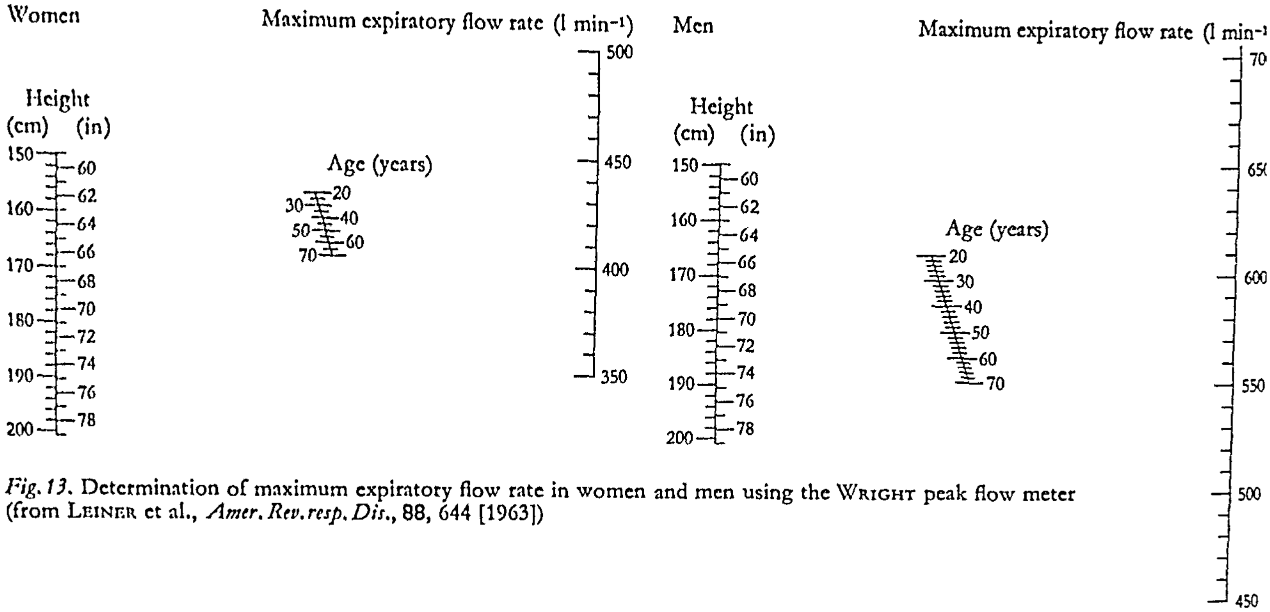


Fig. 13. Determination of maximum expiratory flow rate in women and men using the WRIGHT peak flow meter (from LEINER et al., *Amer. Rev. resp. Dis.*, 88, 644 [1963])

Table 1 Respiratory frequency, tidal volume, minute ventilation and respiratory time quotient in children and adults*

	Respiratory frequency (min^{-1})		Tidal volume (ml)		Minute ventilation ($l\ min^{-1}$)		Respiratory time quotient		Reference
	Mean	95% range (extreme range in brackets)	Mean	95% range (extreme range in brackets)	Mean	95% range (extreme range in brackets)	Mean	95% range (extreme range in brackets)	
Newborn, 4–6 days	49.7	(28.0–69.0)	17.3	(9.5–25.9)	0.83	(0.50–1.48)	1.29	(0.97–2.09)	1
Infants, 11 weeks	62.8	(40.0–87.0)	17.5	(11.0–28.1)	1.03	(0.75–1.37)	1.27	(1.09–1.58)	1
Children, 2–3 years	23.7	(18.9–30.3)	122	(77–149)	2.8	(2.3–4.0)	1.46	(0.92–1.79)	1
Children, 4–5 years	23.2	(11.3–30.2)	138	(147–275)	4.0	(3.1–4.7)	1.43	(1.27–1.55)	1
Children, 6–7 years	21.1	(17.4–24.0)	203	(180–223)	4.3	(3.7–4.9)	1.60	(1.15–2.52)	1
Boys, 12 years	16.3	7.9–24.7	305	185–425	4.8	3.7–5.8	–	–	2
Girls, 12 years	16.1	9.8–22.4	289	189–389	4.5	3.1–6.0	–	–	2
Boys, 14 years	17.0	12.8–21.2	316	196–436	5.3	3.8–6.8	–	–	2
Girls, 14 years	15.6	11.4–19.8	315	235–395	4.9	3.6–6.1	–	–	2
Boys, 16 years	15.6	9.3–21.9	344	184–504	5.1	3.4–6.8	–	–	2
Girls, 16 years	15.2	8.9–21.5	282	162–402	4.2	2.5–5.9	–	–	2
Adults, 20–39 years	17.2	–	–	–	8.5	2.5–14.5	1.35	0.79–1.91	3
Adults, 40–59 years	16.9	–	–	–	9.5	–	1.33	0.85–1.81	3
Adults, 60 years and over	16.3	–	–	–	10.5	–	1.54	0.98–2.10	3
Men, resting	11.7	(10.1–13.1)	630	–	7.4	(5.8–10.3)	–	–	4
Men, light work (500 m kg min^{-1})	17.1	(15.7–18.2)	1670	–	28.6	(27.3–30.9)	–	–	4
Men, heavy work (800 m kg min^{-1})	21.2	(18.6–23.3)	2030	–	43	(39–45)	–	–	4
Women, resting	11.7	–	390	–	4.6	–	–	–	4
Women, light work (300 m kg min^{-1})	19.0	–	860	–	16.4	–	–	–	4

1 BLÖMER and HAHN, *Z. Kinderheilk.*, 87, 466 (1963).
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* At rest unless otherwise stated.

Table 2 Lung volumes and capacities in resting adults

	50 young men[1] (recumbent)		50 young women[1] (recumbent)		11 men over 50 years[2] (semi-recumbent)	
	Mean	s	Mean	s	Mean	s
Age (years)	22.9	3.3	23.1	3.4	61.5	6.8
Height (in and *cm*)	69.3	2.0	64.3	1.7	66.3	1.9
	176.2	*5.1*	*163.4*	*4.2*	*169.0*	*4.8*
Weight (lb and *kg*)	159.5	24.7	126.2	20.4	145.2	27.4
	72.5	*11.2*	*57.2*	*9.4*	*65.9*	*12.4*
Inspiratory capacity (l)	3.79	0.52	2.42	0.36	2.61	0.61
Expiratory reserve volume (l)	0.98	0.26	0.73	0.19	1.01	0.38
Vital capacity (l)	4.78	0.59	3.14	0.41	3.48	0.48
Residual volume (l)	1.19	0.35	1.10	0.30	2.43	0.50
Functional residual capacity (l)	2.18	0.50	1.82	0.39	3.44	0.74
Total capacity (l)	5.97	0.81	4.24	0.57	5.92	0.57
Relative residual capacity (% of total capacity)	19.8	4.4	25.9	5.0	40.9	7.1

1 From KALTREIDER et al., *Amer. Rev. Tuberc.*, 37, 662 (1938).
2 From GREIFENSTEIN et al., *J. appl. Physiol.*, 4, 641 (1952).

Table 3 Residual volume and vital capacity as functions of age[1]

Age (years)	Number	Vital capacity (ml)		Residual volume (ml)		Residual volume as percentage of total lung capacity (%)		Age (years)	Number	Vital capacity (ml)		Residual volume (ml)		Residual volume as percentage of total lung capacity (%)	
		Mean	s	Mean	s	Mean	s			Mean	s	Mean	s	Mean	s
Men								Women							
9–13	16	2690	520	540	180	17.3	4 3	14–19	2–3	3330	(300)	820	(220)	19.5	(5 0)
14–19	9–10	4030	540	830	340	17.2	4 3	20–29	9–11	3600	390	1290	340	25 7	6.2
20–29	20–26	5440	720	1410	310	20 6	4 0	30–39	3	3460	(380)	1310	(280)	28 0	(5 0)
30–39	15–19	5030	700	1510	360	22.2	4 0	40–49	3–4	3680	(710)	1390	(490)	30 0	(8.7)
40–49	14–17	4530	500	1690	410	26 8	5.2	50–59	4	3250	(370)	1300	(360)	28 8	(4 6)
50–59	18	4650	970	1740	380	27 8	4.4	60–64	2–3	3140	(400)	1200	(280)	29 5	(4 6)
60–75	7–11	3860	810	1760	330	33 9	5.2								

[1] From ZEHNDER, H, *Helv med Acta*, 27, 245 (1960)

Table 4 Vital capacity in children as a function of age and sex[1]

Age (years)	Number	Height (in)	Height (cm)	Vital capacity (ml)* Mean	s	Extreme range	Age (years)	Number	Height (in)	Height (cm)	Vital capacity (ml)* Mean	s	Extreme range
Boys							Girls						
4	6	40 7	*103 4*	855	–	540– 970	4	9	37.5	*95.4*	717	–	380– 920
5	20	42 0	*106 8*	1001	–	650–1240	5	26	41.9	*106 4*	959	–	650–1300
6	62	44 2	*112 2*	1246	197	860–1730	6	62	43 8	*111.5*	1172	176	760–1730
7	112	46 0	*116.9*	1393	210	970–2380	7	81	45 0	*114 4*	1326	196	970–1940
8	98	47 9	*121 8*	1585	238	1130–2270	8	76	47.6	*121.0*	1513	215	860–2100
9	110	51 1	*129 9*	1852	266	1300–2480	9	73	50.0	*127 0*	1634	247	1080–2430
10	87	52 5	*133.4*	2022	283	1510–2860	10	117	52.0	*132.1*	1806	295	970–2590
11	113	54 2	*137 8*	2150	292	1400–3020	11	119	53 4	*135.9*	1943	260	1350–2750
12	114	56 1	*142.4*	2357	367	1400–3560	12	135	56 7	*144 0*	2217	370	1510–3130
13	132	58 4	*148 7*	2655	464	1840–4300	13	162	59 6	*151.4*	2537	442	1670–3890
14	177	60 9	*154 8*	2929	523	1510–4640	14	192	61 6	*156 6*	2816	390	2050–4100
15	155	62 9	*159 9*	3397	595	2000–4750	15	131	62 1	*157 8*	2918	446	2050–4000
16	67	65 8	*167.2*	3699	619	2270–4640	16	29	63 0	*160 1*	3000	–	2210–3780
17	23	67 4	*171 4*	4078	–	2590–4860	17	7	64 0	*162 6*	3178	–	2430–3670

[1] From STEWART and SHEETS, *Amer J Dis Child*, 24, 83, 451 (1922)
* Original values increased by 8% as an approximate conversion to BTPS (cf BERNSTEIN et al, *J Allergy*, 30, 514 [1959])

Table 5 Ratios of vital capacity (VC), residual volume (RV), total lung capacity (TLC) and forced expiratory volume ($FEV_{1.0}$) to the cube of the height, and other ratios (volumes in litres, heights in metres)[1]

Age (years)	$\frac{VC}{H^3}$	$\frac{RV}{H^3}$	$\frac{TLC}{H^3}$	$\frac{100\,RV}{TLC}$	$\frac{FEV_{1.0}}{H^3}$	$\frac{FEV_{1.0}}{VC}$
18–19	0 990	0 240	1 230	19 5	0 812	82 0
20–29	1 025	0 275	1 300	21 0	0 818	80 0
30–34	1 020	0 300	1 300	22 5	0 795	78 0
35–39	1 010	0 310	1 320	23 5	0 778	77 0
40–44	1 000	0 320	1 320	24 3	0 757	75 5
45–49	0 990	0 330	1 320	25 0	0 737	74 5
50–54	0 970	0.350	1 320	26 5	0 713	73 5
55–59	0 950	0 370	1 320	28 0	0 684	72 0
60–64	0 930	0 390	1 320	29 5	0 651	70 0
2 V × 100*	17%	31%	22%	11%	19%	13%
Number	3153	1098	1098	1098	2536	2536

* V = Coefficient of variance (see page 159).

[1] From CARA and MARTIN, in DENOLIN et al (Eds.), *L'exploration fonctionnelle pulmonaire*, Flammarion, Paris, 1964, page 112

Table 6 Maximum expiratory flow rate (MEFR) in children and adults

Age (years)		Number	Method	MEFR ($l\,s^{-1}$) Mean	s	Reference
Children	3–5	30	Pneumotachograph	1,8	0 4	1
Men	9–13	16	HADORN pneumatometer	5 0	0 8	2
	14–19	10		7 1	1.3	2
	20–29	20		8 0	0 9	2
	32–39	16		7 9	1.1	2
	40–49	16		7 6	1 0	2
	50–59	17		7.3	1 2	2
	60–75	11		6 8	1 2	2
Women	14–19	3		5 5	(0 9)	2
	20–29	11		5 8	0 7	2
	30–39	3		6 0	(0 8)	2
	40–49	4		5 1	(0 6)	2
	50–59	4		4 6	(0 5)	2
	60–64	3		5 0	(0 2)	2
Adults	40	37	'Minimus' pneumatometer	6 85	1 89	3

[1] RIVERA and SNIDER, *Pediatrics*, 30 117 (1962)
[2] ZEHNDER, H, *Helv med Acta* 87, 245 (1960)
[3] FABEL and HAHN, *Dtsch med Wschr*, 87, 2361 (1962)

Table 7 Diffusing capacity of the lungs (D_L) in resting subjects

Method		Number	Age (years)	D_L (ml min^{-1} mm Hg^{-1})		Reference	Remarks
				Mean	95% range (extreme range in brackets)		
CO methods	'Steady state' method	5	23–45	17	(10.5–28.0)	1	Calculation of mean alveolar CO pressure
	'Steady state' method	18	18–41	17.6	(10.5–28.7)	2	Measurement of CO pressure in expired alveolar air
		7	26–36	20.6	9.6–31.6	3	
	Single-breath method	28	8–72	24.9	(11.0–37.5)	4	Breath-holding for 10 s
		20	4–13	17.4*	4.8–30.0	5	
		3	24–46	35.6	(28.4–41.6)	6	
	Continuous breathing method	15	24–60	25	(19–31)	7	Using ^{14}CO
O_2 methods	'Steady state' method	6	28–36	21	(12–36)	8	
		9	22–28	47	–	9	
	Single-breath method	5	24–46	33	(23–45)	6	Using $^{17}O_2$

* Dependent on body surface area:

Surface area (m^2)	D_L	Surface area (m^2)	D_L
0.8	12.8	1.4	25.4
1.0	17.0	1.6	29.6
1.2	21.2	1.8	33.8

1 Filley et al., *J. clin. Invest.*, 33, 530 (1954).
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Table 8 Respiratory resistances in children and adults

	Number	Age (years)	Resistance (cm H_2O s l^{-1})		Reference
			Mean	*s*	
Airway resistance	5	4–6	1.93	0.5	1
	5	10–13	1.49	0.2	1
	5	10	2.26	0.73	2
	21	22–57	1.50	0.49	3
	12 men	24–46	0.96	0.27	2, 4
	7 women	18–30	1.46	0.47	2, 4
Pulmonary tissue resistance	5	10	1.31	0.37	2
	12 men	24–46	0.29	0.12	2, 4
	7 women	18–30	0.50	0.15	2, 4
Total pulmonary resistance	5	10	3.57	0.98	2
	12 men	24–46	1.25	0.28	2, 4
	7 women	18–30	1.96	0.45	2, 4
	11	18–47	1.9	0.6	5
	21	50–89	2.8	0.8	5
	7	26–36	1.7	1.1	6
	36	–	2.59	0.68	7
Thoracic tissue resistance	36	–	1.37	0.63	7
Total respiratory resistance	36	–	3.96	0.65	7

1 Giammona and Daly, *Amer. J. Dis. Child.*, 110, 144 (1965).
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Table 9 Compliance of the lungs (C_L) in resting adults and children

Number	Age (years)	C_L (ml cm H_2O^{-1})		Reference	Remarks
		Mean	*s*		
11	18–47	150	27	1	
21	50–89	131	38	1	
12	39	213	60	2	Respiratory frequency 20/min
7	26–36	189	34	3	
12 men	24–46	260	60	4	
7 women	18–30	160	50	4, 5	
5	10	83	10.2	5	

1 Frank et al., *J. clin. Invest.*, 36, 1680 (1957).
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Table 10 Work of breathing per breath per millilitre tidal volume in adults[1]

	g cm ml^{-1}	
	Mean	*s*
Total inspiratory work	2.40	0.50
Elastic inspiratory work	1.80	0.35
Nonelastic inspiratory plus nonelastic expiratory work	1.40	0.30

1 Hamm and Schölmerich, *Klin. Wschr.*, 42, 1108 (1964).

Blood pressure in various vessels (mm Hg)[1]

	Systolic pressure		Diastolic pressure		Mean pressure		Method
	Mean	Range	Mean	Range	Mean	Range	
Right atrium	–	–	–	–	3.5	2.5–6.0	Right heart catheterization
Left atrium	–	–	–	–	6.6	6–9	Left heart catheterization
Right ventricle	25	17.0–31.5	0	−0.5 to +7.0	–	–	Right heart catheterization
Left ventricle	120	105–150	0	−0.5 to +7.0	–	–	Left heart catheterization
Pulmonary artery ...	20	11–29	9	4–13	–	8–19	Right heart catheterization
Pulmonary arterioles	15	–	5	–	–	5–13	Right heart catheterization
Pulmonary veins. ..	4	–	8	–	5	3–8	Left or right heart catheterization
Vena cava	–	–	–	–	−1	−5 to +4	Right heart catheterization

Arterial blood pressure

Various methods of measuring blood pressure have been proposed[2–6], and special techniques have been developed for children[7].

... as well as by the World Health Organization[8]. Comparison with intra-arterial measurements has shown that in persons of normal weight the auscultatory method gives readings variously

...

in full-term infants[15]. In children the arterial blood pressure increases gradually with age. Between 12 and 14 years, however, the diastolic pressure tends to fall[16,17], i.e., in the period when sex differences become well marked. In young persons the arterial blood pressure appears to depend mainly on the degree of maturity[17,18], and abnormally high values in the absence of organic disease point to vasomotor instability. The extent to which the

...

seems to have little effect on the arterial blood pressure, but during very heavy work the systolic pressure often rises to over 180 mm Hg[24], whereas the diastolic pressure increases only slightly. The arterial blood pressure often rises during emotional stress[25]. In early pregnancy it tends to be low but rises towards term[26].

Arterial blood pressure (mm Hg) at various ages

Age	Systolic Men Mean	Systolic Men s	Systolic Women Mean	Systolic Women s	Diastolic Men Mean	Diastolic Men s	Diastolic Women Mean	Diastolic Women s	Reference
1 day	70	5							33
3 days	72	6							33
9 days	73	6							33
3 weeks	77	5							33
3 months	86	5							33
6–12 months	89	14.5	93	9.1	60	10.0	62	9.3	34
1 year	96	15.2	95	11.9	66	12.3	65	15.0	34
2 years	99	12.4	92	12.2	64	12.3	60	11.7	34
3 years	100	12.4	100	11.2	67	11.7	64	8.3	34
4 years	99	10.1	99	10.6	65	5.1	66	9.8	34
5 years	92	6.0	92	6.5	62	7.5	62	6.5	35
6 years	94	6.5	94	7.0	64	7.5	64	7.0	35
7 years	97	6.5	97	7.0	65	7.5	66	7.5	35
8 years	100	6.5	100	7.0	67	7.0	68	7.0	35
9 years	101	6.5	101	7.0	68	6.5	69	7.0	35
10 years	103	6.5	103	7.0	69	6.0	70	6.5	35
11 years	104	6.5	104	7.0	70	5.5	71	6.5	35
12 years	106	6.5	106	7.0	71	5.0	72	7.0	35
13 years	108	6.5	108	6.5	72	5.0	73	7.5	35
14 years	110	6.5	110	6.5	73	5.0	74	8.5	35
15 years	112	7.0	112	7.0	75	5.5	76	9.5	35
16 years	118	12.2	116	12.1	73	10.3	72	9.6	2
17 years	121	12.9	116	11.5	74	9.4	72	9.2	2
18 years	120	12.0	116	11.4	74	10.0	72	8.6	2
19 years	122	15.0	115	11.9	75	10.3	71	8.9	2
20–24 years	123	13.8	116	11.8	76	9.9	72	9.7	2
25–29 years	125	12.6	117	11.4	78	9.0	74	9.1	2
30–34 years	126	13.6	120	14.0	79	9.7	75	10.8	2
35–39 years	127	14.2	124	13.9	80	10.4	78	10.0	2
40–44 years	129	15.1	127	17.1	81	9.5	80	10.6	2
45–49 years	130	16.9	131	19.5	82	10.8	82	11.6	2
50–54 years	135	19.2	137	21.3	83	11.3	84	12.4	2
55–59 years	139	18.8	139	21.4	84	11.4	84	11.7	2
60–64 years	142	21.1	144	22.3	85	12.4	85	13.0	2
65–69 years	143	26.0	154	29.0	83	9.9	85	13.8	36
70–74 years	145	26.3	159	25.8	82	15.3	85	15.3	36
75–79 years	146	21.6	158	26.3	81	12.9	84	13.1	36
80–84 years	145	25.6	157	28.0	82	9.9	83	13.1	36
85–89 years	145	24.2	154	27.9	79	14.9	82	17.3	36
90–94 years	145	23.4	150	23.6	78	12.1	79	12.1	36
95–106 years	145	27.5	149	23.5	78	12.7	81	12.5	36

Venous blood pressure

The venous blood pressure rises with increasing distance from the heart, so that the highest pressure is in the peripheral vessels. It varies according to the position of the vein in relation to the right atrium, a result of the varying effect of gravity. The venous pressure is usually measured in the median basilic vein of the right arm at the level of the tricuspid valve. In the newborn the venous pressure depends on the time of tying of the umbilical cord[29].

Venous blood pressure (mm Hg)[30] (median basilic vein at elbow)

	Mean	Range
Children, 3–5 years	3.4	2.2– 4.6
5–10 years	4.3	2.4– 5.4
Adults, men	7.4	3.7–10.3
women	6.9	4.4– 9.4
Dorsal metacarpal veins	9.6	5.2–12.5
Femoral vein	8.2	7.2– 9.4
Abdominal veins	8.5	5.2–11.8
Long saphenous vein	11.0	8.1–14.0
Dorsal digital veins of foot	12.9	9.1–15.4

Capillary blood pressure (mm Hg) (at base of finger nail, hand at level of heart)

	Mean	Range
Direct measurement[31]		
arterial limb	32	21–48
venous limb	12	6–18
Indirect (bloodless) measurement[32]		
arterioles	47	–
capillaries	27	–

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Blood volume

In men the normal blood volume amounts to 6–8%, in women 5.5–7%, of the body weight (see page 528), depending on the bodily constitution. Of the total quantity, 65–75% is in the venous system, 15–20% in the arteries and 5–7.5% in the capillary bed[1]. Blood volumes given by different authorities should not be compared without careful prior scrutiny of the methods of measurement used. The table on page 555 contains selected blood volume values for children and adults. The literature[1–3] should be consulted for more comprehensive reviews.

The most accurate method of determining the blood volume (BV) is by separate measurement of the plasma volume (PV) and erythrocyte volume (EV):

$$BV = PV + EV \tag{1}$$

A less accurate method is by calculation from the plasma volume and body haematocrit (Ht):

$$BV = 100 \times \frac{PV}{100 - Ht} \tag{2}$$

or from the erythrocyte volume and body haematocrit:

$$BV = 100 \times \frac{EV}{Ht} \tag{3}$$

The body haematocrit is defined as

$$Ht = 100 \times \frac{EV}{PV + EV} \tag{4}$$

and is calculated from the venous haematocrit (Htv):

$$Ht = Htv \times 0.97 \times 0.91 = Htv \times 0.88 \tag{5}$$

The factor of 0.97 allows for the trapped plasma remaining in the erythrocyte column after centrifuging (micro-haematocrit technique[4]), the factor of 0.91 for the lower erythrocyte content in the blood as a whole than in venous blood.

Various methods are available for determining plasma and erythrocyte volume[3,5]. The following indicators are used for plasma volume: Evans blue (T-1824), Coomassie blue[6], dextran, $^{51}CrCl_3$, ^{59}Fe citrate, ^{131}I-human serum albumin, ^{125}I-human serum albumin[7], alkaline phosphatase[8]; indicators for erythrocyte volume are carbon monoxide and erythrocytes tagged with ^{32}P, ^{42}K or ^{51}Cr.

Physiological variations

During the first years of life there are considerable differences between the blood volumes of individual children[9]. Divergences in published values for the blood volume of newborn infants[9–11] and children[12–14] are probably due to differences in the method of measurement. In the newborn the time of tying of the umbilical cord has an effect on the blood volume[11]. Regression equations for the blood volume in children in relation to height, weight and body surface area have been derived[13]. Up to puberty the blood volume

ed that the relationship to body weight in adults is very similar to that in children[1,8].

In adults the blood volume is very closely related to the body

volume, since compared to whites negroes[24] have lower, eskimos[25] higher, blood and plasma volumes

The blood volume is fairly constant, and intake of fluid by either the oral or intravenous route is followed by its very rapid normalization[24]. Bed-rest causes a diminution in the blood volume, mainly ... sports increase both the

[151]

The volume has returned to normal at 3–4 months post partum[28–31].

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Blood, erythrocyte and plasma volumes *(per kilogramme* body weight or square metre body surface area)

	Number	Whole blood				Erythrocytes				Plasma				Ratio body haematocrit venous haematocrit		Method*
		ml/kg		ml/m²		ml/kg		ml/m²		ml/kg		ml/m²				
		Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	
Newborn, 15–30 minutes	50	76 5	7 81	–	–	35 0	5 60	–	–	41 5	3 98	–	–	–	–	T-1824, Ht
Newborn, 24 hours	61	83 3	8 2	–	–	37 7	6 4	–	–	45 6	4 3	–	–	–	–	T-1824, Ht
Children, 3 months	–	87	–	–	–	33	–	–	–	54	–	–	–	–	–	T-1824, Ht
Children, 6 months	–	86	–	–	–	31	–	–	–	55	–	–	–	–	–	T-1824, Ht
Children, 1 year	–	80	–	–	–	28	–	–	–	52	–	–	–	–	–	T-1824, Ht
Children, 6 years	–	80	–	–	–	29	–	–	–	51	–	–	–	–	–	T-1824, Ht
Children, 10 years	–	75	–	–	–	30	–	–	–	45	–	–	–	–	–	T-1824, Ht
Children, 15 years	–	71	–	–	–	30	–	–	–	41	–	–	–	–	–	T-1824, Ht
Men	–	71	–	–	–	33	–	–	–	38	–	–	–	–	–	T-1824, Ht
Women	–	70	–	–	–	29	–	–	–	41	–	–	–	–	–	T-1824, Ht
Men	30	69 1	–	2566	235	28 0	–	1039	123	41 1	–	1527	156	0 950	0 33	T-1824, ^{32}P
Women	30	62 1	–	2245	191	21 6	–	782	80	40 5	–	1463	162	0 930	0 51	T-1824, ^{32}P
Men	8	77 6	–	2857	–	31 7	–	1167	–	45 9	–	1690	–	0 913	0 036	^{131}I HSA, ^{51}Cr
Women	4	78 7	–	2700	–	29 1	–	998	–	49 6	–	1702	–	0 913	0 036	^{131}I HSA, ^{51}Cr
Men	22	77 8	6 6	2873	210	29 9	3 5	1109	111	48 0	4 9	1765	171	–	–	^{131}I-HSA, Ht
Women	12	72 7	13 4	2437	358	24 7	5 1	835	151	47 5	8 7	1586	214	–	–	^{131}I-HSA, Ht
Men, 23–54 years	10	69	–	–	–	27	–	–	–	42	–	–	–	–	–	T-1824, ^{51}Cr
Men, 71–84 years	7	70	–	–	–	25	–	–	–	45	–	–	–	–	–	T-1824, ^{51}Cr
Women, 23–51 years	10	64	–	–	–	22	–	–	–	42	–	–	–	–	–	T 1824, ^{51}Cr
Women, 60–74 years	7	57	–	–	–	20	–	–	–	37	–	–	–	–	–	T 1824, ^{51}Cr

* T 1824 = Evans blue, ^{131}I-HSA = ^{131}I human serum albumin, Ht = haematocrit

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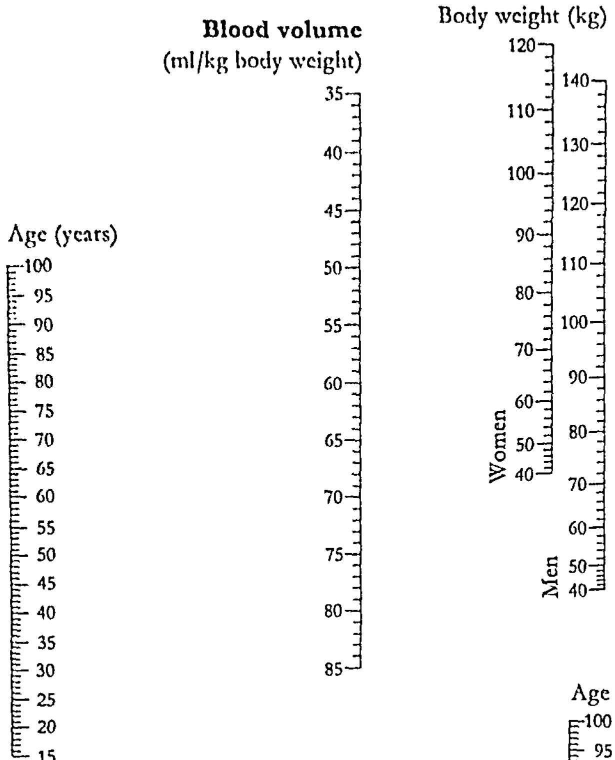
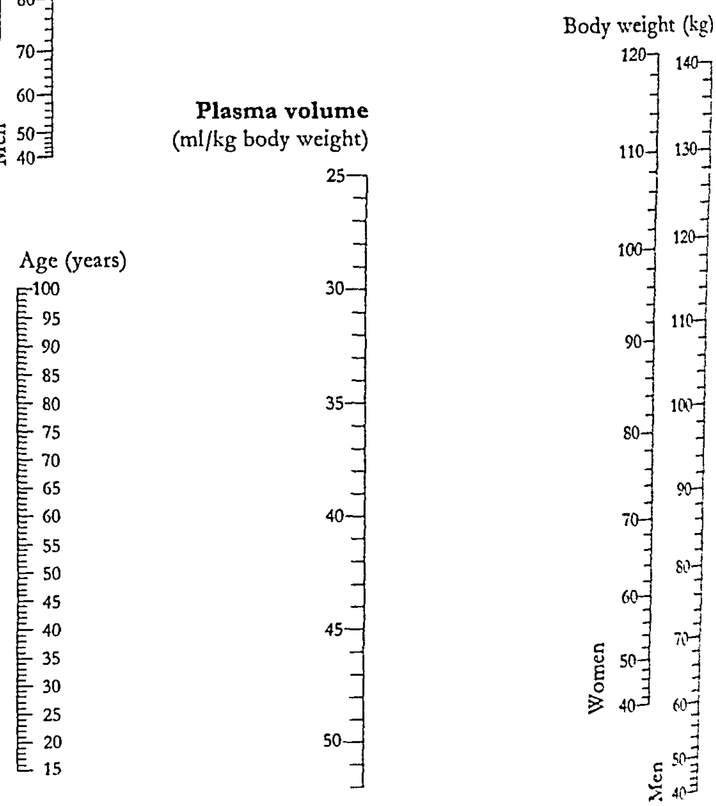
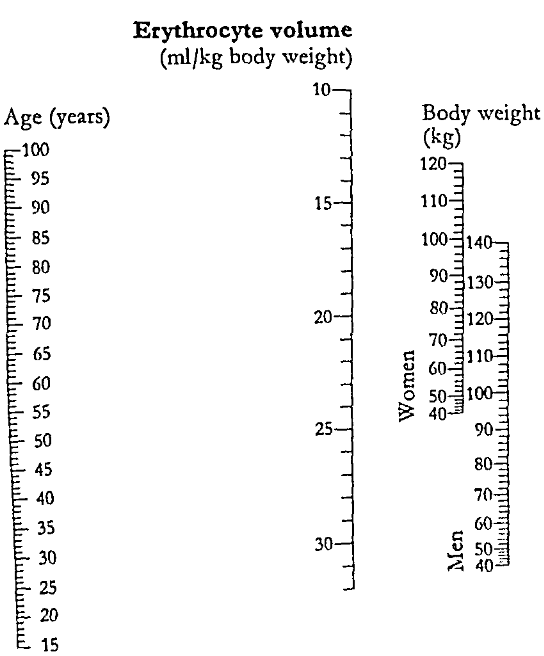
Nomogram for obtaining blood, plasma and erythrocyte volumes from the age and body weight of adults [DAGHER et al., *Advan Surg.*, 1, 69 (1965)]







(For references see page 561)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
pecific gravity (25 °C/4 °C)					
) Whole blood, men	1 0595	1.0553–1 0637	0 0021	1	
) Whole blood, women ..		(1 0523–1 0604)		1	
) Plasma, men	1 0269	1 0251–1 0287	0 0009	1	lower in the afternoon and after meals, rather higher at night and after physical effort The plasma specific gravity is pathologically *increased* in cholera, dysentery, severe burns and plasmacytoma, *decreased* in hydropic renal disease, the specific gravity of whole blood is pathologically *decreased* in anaemia
Serum	–	(1 024–1.028)	–	2	
) Erythrocytes, men	1.0964	1.0928–1.1000	0 0018	1	
Leucocytes	–	(1 07–1 08)	–	3	
Thrombocytes	1 03	–	–	4	
reezing-point depression (°C)					
a) Serum	0.540	0 512–0 568	0.014	7	Measured on (a) 75, (b) 50 subjects Values in whole blood and serum are almost identical The erythrocytes are in osmotic equilibrium with the serum[9].
b) Serum	0 537	–	–	8	
smolality (mosm/kg H_2O)					
erum . . .	289	281–297	4	6	
smotic pressure (at 0 °C)					
erum (atm) ..	6.51	–	–	–	Calculated from the values (a) for the freezing-point depression (using the table on page 272) The osmotic pressure is mainly accounted for by the crystalloid components, the colloids contribute only about 0 5% of the total osmotic pressure
erum (mm Hg) .	4950	–	–	–	

Specific gravity/Serum water/Solutes[22]

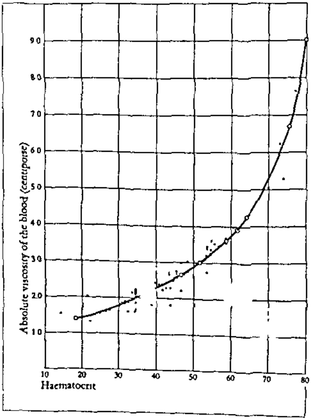
The table can be used to convert

(a) the concentration of a substance per litre serum into its concentration per kilogramme serum water Multiply by the factor in column 4

(b) the concentration of a substance per kilogramme serum water into its concentration per litre serum Multiply by the figure in column 3 and divide by 1000

Specific gravity	Water per kilogramme serum (g)	Water per litre serum (g)	Factor
1	2	3	4
1 015	952	966	1 035
1 016	948	964	1 038
1 017	945	961	1 040
1 018	942	959	1 043
1 019	939	957	1 045
1 020	936	954	1 048
1 021	932	952	1 051
1 022	929	949	1 053
1 023	926	947	1 056
1 024	923	945	1 059
1 025	919	942	1 061
1 026	916	940	1 064
1 027	913	938	1 067
1 028	910	935	1 069
1 029	906	933	1 072
1 030	903	930	1 075
1 031	900	928	1 078
1 032	897	925	1 081
1 033	894	923	1 083
1 034	890	921	1 086

Relationship between haematocrit and blood viscosity[17]



(For references see page 561)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Colloid-osmotic (oncotic) pressure (at 0 °C)					
Serum (mm Hg)	24.3	(20.6–35.3)	–	12	The colloid-osmotic pressure (COP) can be calculated approximately fro the albumin and globulin contents by using the formula of Keys[13] (see pa 526). Exact calculation requires measurement of the COP of the individu serum protein fractions[14]. The major part of the COP is accounted for b albumin; fibrinogen has no measurable effect on the COP of the plasma[15], s that the COP of the plasma can be equated with that of the serum.
Viscosity					
Relative viscosity (in vitro at 18 °C)					
(a) Whole blood	4.75	(3.80–5.70)	–	16	Measured on (a, b) 21, (c) 25 fasting subjects with the Hess viscosimeter; (in vivo by means of capillaries on subjects with a haematocrit of 40–45%; (with the Zeitfuchs capillary viscosimeter. Since blood is a non-Newtonia fluid, viscosity values measured by different methods are not comparable. Th dependence of the dynamic viscosity on the shear rate between 10 and 200 s⁻ has been studied by means of a cone-plate viscosimeter[19]; for any give haematocrit value the viscosity falls with increasing shear rate. The in viv viscosity values (d) correspond to a shear rate of ca. 1700 s^{-1}. The rheologica properties of blood have also been studied in vivo[20]. For determination c viscosity by the falling-ball viscosimeter see Krosch and Heidelmann[21]. The viscosity of whole blood depends mainly on the cell content, i.e., i healthy subjects on the erythrocyte content (see the diagram on page 557) that of plasma on the protein content. The relative viscosity of whole blood i about 0.5 higher in men than in women[23, 39], while in children it is rather lowe than in adults[39]. The relative viscosity of venous blood is higher than that o arterial blood[39]. The viscosity of whole blood is pathologically *increased* i polycythaemia vera[24], sickle-cell anaemia[25] and leukaemia[26], that of the serum is *increased* in hyperglobulinaemia[18, 27], in the presence of a high titr of the rheumatoid factor[18], and particularly in macroglobulinaemia[18, 27].
(b) Plasma	2.01	1.67–2.35	0.17	16	
(c) Serum	1.88	1.58–2.18	0.15	16	
Dynamic viscosity (centipoise) (in vivo)					
(d) Whole blood	–	(2.30–2.75)	–	17	
Kinematic viscosity (centistoke) (in vitro at 37.5 °C)					
(e) Serum	1.15	(1.08–1.22)	–	18	
Erythrocyte sedimentation rate (sedimentation rate, ESR)	...	...	...	...	Values depend on the method of measurement (see the table below and text opposite).
Leucocyte sedimentation index (LSI) (mm/h)	13.58	3.72–23.4	4.93	28	Calculated from the formula $\frac{1}{2}(a+b/2)$, where a = mm sedimentation in 1 hour, b = mm sedimentation in 2 hours; values from 300 adults. In the method used, a sample of leucocyte-rich plasma is layered on top of cell-free plasma. The LSI is dependent on the properties of the leucocytes but not on those of the plasma; immature leucocyte forms appear to settle out faster. The LSI is increased in acute forms of leukaemia, acute Hodgkin's disease, tuberculosis and other bacterial infections, and in carcinoma with liver metastases.

... sedimentation rate

Methods

	Westergren methods: Original[70]	Westergren methods: 'Wide tube' modification[71]	Westergren methods: Wintrobe's modification[39]	Linzenmeier's method[72]
Sedimentation tube				
Blood column	200 mm	100 mm	100 mm	50 mm
Diameter	2.5 mm	5 mm	2.5 mm	5 mm
Anticoagulant	Sodium citrate 3.8% solution	Sodium citrate 3.8% solution	2 parts potassium oxalate + 3 parts ammonium oxalate dry	Sodium citrate 5% solution
Quantity (mg/100 ml mixture)	760	760	200	1000
Resulting dilution of blood	20%	20%	0	20%

Normal values (mornings, fasting)

	Sedimentation after: 1 hour (mm)	2 hours (mm)	24 hours (mm)	1 hour (mm)	2 hours (mm)	1 hour (mm)		Time for a sedimentation of 18 mm (h)	
	Range	Range	Range	Range	Range	Mean	Range	Mean[75]	Range[75]
Newborn, 1st day	Up to 2[73]	–	–	–	–	–	Up to 2[73]	106	30–185
Newborn, 4th day	–	–	–	–	–	–	–	45	6–120
Newborn, 12th–21st day	–	–	–	–	–	–	–	11	2–40
Males, 12–20 years	–	–	–	–	–	4.7[74]	Up to 20[74]	–	–
Men..................	3–5	Up to 15	90	2–5	5–14	3.7	Up to 6.5	10	–
Women...............	3–8	Up to 20	100–110	3–8	6–18	9.6	Up to 15	–	3½–5

(For references see page 561)

hrocyte sedimentation rate (ESR)

ie mechanism of erythrocyte sedimentation[29, 30] is only partly rstood. Three phases can be distinguished. In the first phase

he rate of sedimentation depends on the extent to which the agglomerate. The cause of the adherence of the cells is rever- adsorption of certain plasma proteins by so-called sedimenta- receptors on the cell surface. These receptors probably consist cerebroside[31], while the plasma proteins involved can be ded into so-called agglomerins[32] and a supplement[33]. Except n they are present at very high concentrations, the agglomerins

ma are present when the sedimentation rate is increased

is lysophosphatide attaches itself to the serum albumin to form albumin-lipid complex that inhibits sedimentation of the eryth- ytes.

The biological significance of an increase in the sedimentation is still obscure. Since a number of substances that inhibit in- nmation also inhibit an increase in the sedimentation rate in

Other factors affecting the sedimentation rate are

size, shape (sickle-cell erythrocytes have a lower sedimentation rate than normal erythrocytes), haemoglobin content and number of the erythrocytes,

length of the column of blood (a short column shows a slower

rate)

Physiological variations The sedimentation rate is more constant men than in women, this is not due to the menstrual cycle, anges during which are small and of no clinical significance[29]. In egnancy, the rate begins to increase at the 3rd to 4th month and es not return to normal until the 3rd or 4th week post par- m[39, 40]. In the newborn the sedimentation rate is greatly reduced ee the table on page 558), in older adults rather high[41].

Pathological variations The sedimentation rate is reduced in poly- thaemia, congestive heart failure, diseases of the liver parenchyma,

Guiding principles in practice[29]

picture, 20–30 hours usually elapse before a change in the sed mentation rate is observed.

2 Daily fluctuations in the sedimentation rate are insignifican usually it is sufficient to measure the 1- and 2-hour values. I any particular blood sample the measured values vary fro method to method. Values show marked differences in any or individual, so that a knowledge of his minimal values when i good health is important.

3 A marked increase in the sedimentation rate is an objectiv

essential.

4 An exceptionally large and rapid increase in the sedimentatio rate reaching a maximum in 15–20 minutes points strongly t a plasmacytoma or macroglobulinaemia.

5. A marked and persistent increase in the sedimentation rate tha cannot be otherwise accounted for should raise suspicion of carcinoma. In these circumstances the patient should continu to be examined at intervals until the cause of the increase i revealed.

6 A normal sedimentation rate never excludes the possibility c disease, even a severe progressive one such as tuberculosis o

observed in vagotonia.

7 In rare cases a marked increase in the sedimentation rate i accompanied by a completely normal plasma protein pattern for instance in decompensated pernicious anaemia. There is no correlation, however, between the sedimentation rate and th fibrinogen, globulin or total protein content of the blood.

8

9 The sedimentation rate is often less affected by the disease itsel than by the secondary complications, such as pneumonia thrombophlebitis, infarction of the lung, intercurrent infections etc. Anticoagulant therapy often delays normalization of th sedimentation rate for a considerable time. While drugs i general have no direct effect on the sedimentation rate the may have a secondary effect due to damage to the liver paren chyma.

10 Measurement of the sedimentation rate provides an opportunit of examining the plasma for colour and clarity (golden-yellov in haemolysis, unusually clear in iron deficiency, straw-coloure

naked eye

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
urface tension (20 °C, dyn cm⁻¹)					
erum	56.2	–	–	42	Values measured by torsion balance in 82 fasting subjects between 20 and 3(years of age
lefractive index (20 °C)	–	(1.34846–	–	43	

	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks
Specific heat (cal deg^{-1} g^{-1})					
Whole blood	0.87	–	–	45	
Plasma	0.94	–	–	45	
Erythrocytes	0.77	–	–	45	
Specific conductivity (25 °C, S cm^{-1})					
Serum	0.01190	(0.01173–0.01229)	–	46	*The specific conductivity and total protein content of the serum can be* u *to calculate the total cations (see page 562).*
Electrophoretic mobility (anodic) (μm s^{-1} V^{-1} cm)					
(a) Erythrocytes	1.080	1.064–1.096	0.008	47	Values from (a) 10 subjects (pH 7.2 in phosphate-buffered saline), (b) 28 s jects (citrated blood). The electrophoretic mobility of blood cells is determi mainly by the carboxyl groups of the sialic acid present on the cell surface[49]. Each type of cell has a characteristic mobility; that of the erythrocytes is in pendent of race, sex, age and blood grouping[52]. The leucocytes have an creased mobility[48, 51] in chronic and acute myelosis, lymphadenosis, Ho KIN's disease and in the presence of tumours with bone metastases. Eryth cytes have a lower mobility in the serum of cancer patients[53].
(b) Erythrocytes	1.270	1.236–1.304	0.017	48	
(b) Granulocytes	0.840	0.790–0.890	0.025	48	
(b) Lymphocytes	1.060	1.006–1.114	0.027	48	
(b) Thrombocytes	0.120	0.020–0.220	0.050	48	
Surface density of electric charge (esu cm^{-2})					
Erythrocytes	3500	–	–	50	Calculated from the electrophoretic mobility. Assuming the erythrocyte s face to be 163 μm^2, the electric charge per erythrocyte is 11.9 × 10^6 esu.
Redox potential (mV)					
Whole venous blood					
(a) To calomel electrode	–	−260 to −300	–	54	The range given embraces 83% of 550 measurements made in vitro by t method of ZIEGLER[55] using a weakly polarized platinum electrode. The red potential of blood is determined by the ratio of dehydroascorbic acid ascorbic acid.
(b) To hydrogen electrode	–	−12 to −52	–	54	
pH value (38 °C)					
(a) Umbilical artery, whole blood	7.21	(7.05–7.38)	–	56	Values from (a) 19, (b) 12, (c) 13, (d) 15, (e) 29, (f, g, h, k) each 20, (i) 55 ar (j) 9 subjects measured by pH electrode; values (d, f, g, h, k) are on the NI pH scale, values (e, j) on the HITCHCOCK-TAYLOR pH scale. On the theoretical basis of pH measurement see page 278. The clinical measur ment of pH has been much discussed[60, 65–67]. pH values are comparable on when the nature of the standard buffer used is known; use of the Nation Bureau of Standards buffer scale is recommended (for the NBS pH scale s page 279). Measurements should be made at 37 °C and not 38 °C[64]. Hepar is a suitable anticoagulant, but not oxalate, citrate or EDTA[66]. In completely resting subjects there is no difference between the values i plasma and whole blood[65], but during bodily activity the arterial plasma slightly more alkaline than the arterial whole blood (maximum difference 0.I pH units at an oxygen saturation of 98%). The pH value of the capillary bloo is almost the same as that of the arterial blood[59, 60], the former being on th average 0.008 pH units more alkaline than the latter. In the limbs the venou plasma is up to 0.03 pH units less alkaline than the arterial plasma[59]. In th newborn the blood pH is low[56, 68], in pregnant women rather high[69]. In acute disturbances of acid–base balance the blood pH may briefly fall t 6.8 or rise to 7.8[60]; in chronic diseases it usually lies between 7.2 and 7.5 The pH value of the blood is extremely low in diabetic coma and severe ren insufficiency, very high in acute hyperventilation accompanied by anaesthesi and following protracted loss of hydrogen ions, for instance in vomiting.
(a) Umbilical vein, whole blood	7.32	(7.23–7.42)	–	56	
Arterial whole blood					
(b) Infants, 1–4 weeks	7.377	7.315–7.439	0.031	57	
(c) Infants, 4–16 months	7.432	7.366–7.498	0.033	57	
(d) Adults	7.424	7.386–7.462	0.019	58	
(e) Adults	7.392	–	–	59	
Capillary whole blood					
(f) Men	7.390	7.360–7.420	0.015	60	
(g) Women	7.398	7.366–7.430	0.016	60	
Arterial plasma					
(h) Adults	7.39	7.35–7.43	0.018	61	
Venous plasma					
(i) Adults	7.398	7.378–7.418	0.010	62	
Erythrocytes					
(j) Adults	7.209	7.175–7.243	0.017	63	
(k) Adults	7.19	7.15–7.23	0.022	61	
Capillary whole blood (37 °C)					
(f) Men	7.405	7.375–7.435	–	64	
(g) Women	7.412	7.391–7.435	–	64	

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norganic substances *(for references see pages 567–568)*

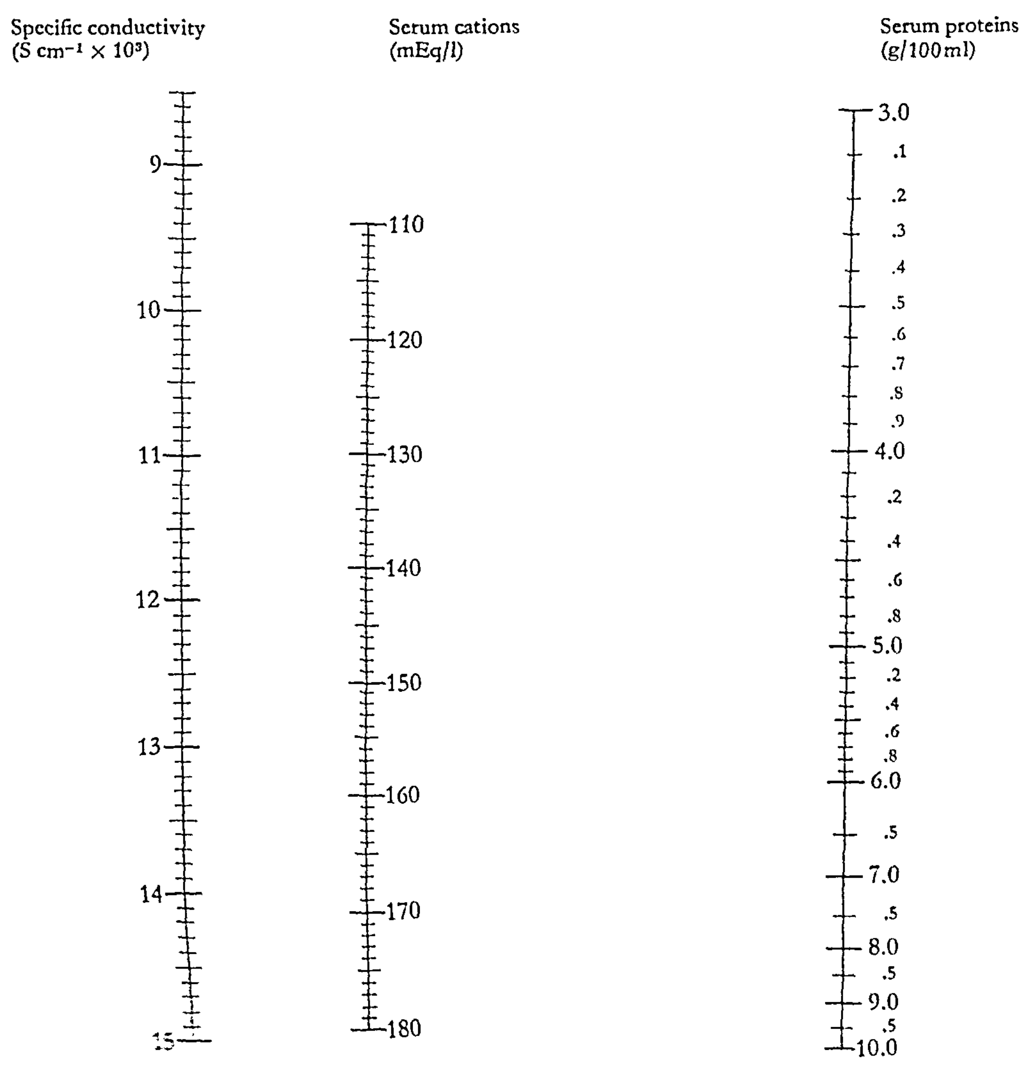
	Whole blood Mean	95% range (extreme range in brackets)	s	Reference	Plasma or serum Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Water									
(g/l)	850	(830–865)	–	1	945	(930–955)	–	1	Values (a) from 124 subjects. The water content of the erythrocytes increases as the haemoglobin content falls. The water content of the plasma is highest in resting recumbent subjects and increases during physical effort. The water content of the leucocytes varies with the type and degree of maturity.
(g/l)	713	Erythrocytes 693–733	10	2					
(g/kg)	691.3	654–709	13.6	3					
(a) (g/kg)	666	643–624	9.0	127					
Dry substance									
(a) (g/l)	205	–	–	–	80	–	–	–	Values (a) calculated from the water content and specific gravity, (b) measured in 123 subjects. About 90% of the dry substance of whole blood consists of organic substances
(b) (g/kg)	334	Erythrocytes 316–352	9.0	127					
Total cations									
(a) Arterial blood (mEq/l)	..	..	...	..	152.9	140–157	2.2	6	Values (a) from 44 men by electrodialysis, (b) calculated by addition of the potassium, sodium, magnesium and calcium ions. The total serum cations are increased in premature infants during the
(a) Venous blood (mEq/l)	..	..	..	.	154.1	140–159	2.6	6	
(b) (mEq/kg H_2O)	176	Erythrocytes –	–	3	163	–	–	3	

(For references see pages 567–568)

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Bicarbonate (mEq/l)......	11.2	Erythrocytes: 10.9–11.5	0.15	8	24.9	· 21.3–28.5	1.79	9	Erythrocyte values from ! values from 15 subjects. See : 'Blood Gases', page 571.
Chloride (mEq/l)									
(a) Umbilical vein blood ...	...	...	...	...	103.3	94.1–113	4.6	10	Values from (a) 14, (b) 20, (c 157, (f) 37 subjects measured metrically, (b, c) mercurimetri argentometrically. An autor perometric method of chlorid nation has been described[16]. whole blood comes into cor air, CO_2 passes out of the ery and is replaced by chloride plasma (chloride shift); in de serum chloride the erythrocyt therefore be separated as far a with the exclusion of air.
(a) Newborn, 2 days.......	...	...	...	...	102.8	88.6–117	7.1	10	
(b) Infants, 3 months	...	...	...	...	113.6	83.2–144	15.2	11	
(c) Adults	–	(77–88)	–	12	102.7	(99–110)	–	12	
(d) Adults	...	...	...	...	106	101–111	2.5	13	
(e) Adults	–	Erythrocytes: (52–65)	–	14					
(f) Adults	67.9	58.9–76.9	4.5	15					

The chloride content of cord blood is roughly the same as that of the maternal blood[17]; that of the serum rather higher in infants than in adults[11].
The serum chloride level is pathologically *increased* after protracted dehydration, in renal hyperchloraemic acidosis (Lightwood and Albright types), in respiratory alkalosis, after head injuries and during treatment with corticosteroids; it is *decreased* by severe sweating without adequate chloride intake, by loss of digestive juices (especially gastric juice), by burns, by expansi extracellular fluid (pneumonia, water intoxication), in injury to tubules, in adrenocortical insufficiency (Addison's disease), during m with certain diuretic agents, in respiratory acidosis and occasionally i ketosis accompanied by diuresis.

Nomogram for obtaining the serum cation concentration from the specific conductivity and protein content of the serur
Lufkin and Sunderman, *Techn. Bull. Registry med. Technologists*, 7, 118 [1946], supplement to *Amer. J. clin. Path.*, 16 [1946])



(For references see pages 567–568)

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
hosphorus (mg/l)									
) Total phosphorus	370	(314–443)	–	18	112	(89–149)	–	18	Values from (a) 42, (b) 464, (c) 121, whole blood) 42, (d, serum) 22, (e) (f) 42, (g, erythrocytes) 20, (g, seru 42 subjects, values (f) exclude lipid pho phorus. The phosphorus of the erythrocytes co sists mainly of phosphoric acid este (nucleotides, sugar phosphates and gly erol diphosphate), with only sm amounts of inorganic phosphate In t serum, lipid phosphorus predominat (see under 'Phosphatides', page 601). *Serum inorganic phosphate* Determinatio should be made in fasting serum. F methods see the literature[24]. The seru phosphate consists of about 80% p mary phosphate and about 20% seco dary phosphate, depending on the pl small amounts are protein-bound[25]. The serum phosphate level is high du ing the first days of life[17 19 26], in ch dren it is markedly higher than in adul but falls to the adult level when ossi cation of the skeleton is complete[27 …]. The level begins to increase at about t age of 50[28] In men and women t levels are about the same[28] except du ing pregnancy, when there is a marke reduction[29] On phosphate metabolis see the literature[30]. The serum phosphate level is patholog ically *increased* in hypoparathyroidis pseudohypoparathyroidism, renal insu ficiency, vitamin D intoxication, and o casionally in idiopathic hypercalcaemi it is *decreased* in hyperparathyroidis impaired calcium and phosphate absorp tion, vitamin D-deficient rickets, ren tubular acidosis (ALBRIGHT type), th FANCONI syndrome and phosphate dia betes
	Erythrocytes								
	719	(609–867)	–	18					
iorganic phosphorus		Whole blood							
ɔ) Newborn, 1 week	.	..	...	..	60 3	(37–85)	–	19	
:) Juveniles, 1–19 years	...	..	. .	...	48	(36–59)	–	20	
l) Adults	29	(21–38)	–	18	33 6	25 6–41.6	4 0	21	
		Erythrocytes							
ɪ)	24	(9.1–33)	–	18					
ε)	2.7	0 5–4 9	1 1	22					
		Whole blood							
f) Phosphoric ester phosphorus	231	(186–286)	–	18	34	(25–45)	–	18	
		Erythrocytes							
	497	(385–587)	–	18					
		Erythrocytes							
g) *Lipid phosphorus*	137	124–150	6 5	23	83	(69–97)	–	18	
Sulphur (mg/l)									
(a) Total sulphur	1221	–	–	31	780	–	–	–	Plasma values (a) calculated from th whole blood and erythrocyte value values (b) from 16, (c) from 88 youn adults About 95% of the sulphur in blood i contained in the proteins The sulphuri ester fraction contains 3 indoxylsulphu ric acid (see page 575) and other conju gated sulphuric acids, the neutral sul phur fraction includes amino acids, glu tathione, ergothioneine and other com pounds The serum inorganic sulphate level is in *creased in renal failure*[33]
		Erythrocytes							
	1900	–	–	31					
		Whole blood							
(a) Protein sulphur	1180	–	–	31	740	–	–	–	
		Erythrocytes							
	1859	–	–	31					
(b) Nonprotein sulphur					33 8	(29 5–37 5)	–	32	
Inorganic sulphate sulphur					15.7	(10 0–18 5)	–	32	
Sulphuric ester sulphur					3 9	(2 5–6 5)	–	32	
Neutral sulphur					14 2	(9 0–19 5)	–	32	
(c) Inorganic sulphate (mEq/l)					0 65	0 31–0 99	0 17	33	
Bromide (mg/l)	3 72	*(2.27–5 27)*	–	34	*2 8*	*(0 7–13 3)*	–	35	Values (a) from 5 subjects determine by neutron activation The bromid content of the blood appears to fluctuat widely from one individual to another It is increased by medication with bro mine compounds, levels over 2 5 g/ serum are definitely toxic[37].
(a) (mg/kg)	3 9	0–7 9	2 0	36					
Fluoride (mg/l)									
(a)	*0 15*	*(0 04–0 36)*	–	38	–	*(0 14–0 19)*	–	39	Values (a) for whole blood from 37 wom en lower values have been recorded in the newborn and their mothers Serum values from subjects whose drinking
(b)					0 014	–	0 008	120	

Blood – Inorganic Substances

(For references see pages 567–568)

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Iodine (µg/l)									
(a) Total iodine	...	...	...	...	52.1	(38–60)	–	41	Values from (a) 12, (b) 11, (((e) 12, (f) 38, (g) 91, (h) 2' subjects; values determined kaline digestion, (b) ^{132}I trac ric acid digestion, (c–i) pe digestion. For methods see ture[47,48].
(b) Inorganic iodine	...	...	...	...	2.8	(1.0–5.2)	–	42	
Protein-bound iodine									
(c) Cord blood	...	...	...	...	79	(67–92)	–	43	
(a) Adults	...	...	...	...	48.1	(35–56)	–	41	
(d) Adults	...	...	...	...	52	32–72	10	44	
Butanol-extractable iodine									
(e) Newborn, 2–6 days	...	...	...	...	–	(70–117)	–	45	
(f) Children, 1 month–10 years	...	...	...	...	55	39–71	8	46	
(g) Juveniles, 11–18 years	...	...	...	...	42	30–54	6	46	
(h) Men	...	...	...	...	50.0	33.0–67.0	8.5	46	
(i) Women	...	...	...	...	44.6	31.8–57.4	6.4	46	

The inorganic serum iodine level depends on the iodine intake; with a normal intake the serum iodine is almost exclusively organic. The protein-bound iodine consists of the tetra-, tri- and di-iodothyronines and part of the mono-iodothyronine, while the butanol-extractable iodine comprises only tetra- and tri-iodothyronine. The serum protein-bound iodine is higher in and during pregnancy[43,50], and also higher in newborn than in old [43,46]; it is *increased* in hyperthyroidism (80–300 µg/l) and *decrease* thyroidism (0–40 µg/l)[47]. On iodine metabolism see the literature

	Whole blood Mean	95% range	s	Reference	Plasma or serum Mean	95% range	s	Reference	Remarks
Thiocyanate (mg/l)	...	...	...	...	0.80	(0.44–1.14)	–	52	Values from 52 nonsmoker values are found in smokers tients with hyperplasia of the
Borate (as boron, mg/l)	0.25	(0.00–1.25)	–	53	...	...	...	...	Values from 34 children; large due for instance to excessive a through the skin from using preparations, are toxic.
Nitrite (µg/l)	8	(0–16)	–	54					
cate (as SiO_2, mg/l)	8.3	3.5–13.1	2.4	55	...	...	...	...	Values from 264 subjects; no d due to age, sex or disease (incl cosis) were found.
Potassium (mEq/l)		Erythrocytes:							
(a) Umbilical vein blood	99.6	97–102	–	10	7.79	3.79–11.8	2.0	10	Values from (a, erythrocytes) rum) 14, (b) 12, (c) 13, (d, eryt 20, (d, serum) 157, (e) 37, (f, 106, (g, serum) 22, (h) 128, (i jects, all by flame photometry tails of method[59] and the thrombocytes on potassium nation in serum see the literatu
(a) Newborn, 1 day	105	100–108	–	10	6.19	4.73–7.65	0.73	10	
(a) Newborn, 2 days	107	100–114	–	10	5.92	4.32–7.52	0.8	10	
(b) Children, 3 months	...	...	...	...	5.24	4.30–6.18	0.47	11	
(c) Children, 18 months	...	...	...	...	4.72	3.54–5.90	0.59	11	
(d) Adults	81.7	68.3–95.1	6.7	56	4.30	3.40–5.20	0.45	13	
(e) Adults	88	76–100	6	15	4.05	3.37–4.73	0.34	15	
(f) Adults	...	...	...	...	3.7	3.1–4.3	0.31	127	
(g) Adults	...	...	...	...	4.4	3.6–5.2	0.39	127	
(h) (mEq/kg)	89.6	82–97	3.6	127					
		Thrombocytes:							
(i) (mEq/kg)	89.7	73.9–106	7.9	57					
(k) (mEq/kg)	69.1	65–71	–	58					

The potassium content of the cord serum is significantly higher than that of the maternal serum[17]; in infants it is significantly higher than in adults[11]. There is no noticeable change in the potassium level in the blood between the ages of 25 and 97[61].

The serum potassium level is pathologically *increased* by rapid infusion of potassium salts and in massive haemolysis, acute tissue breakdown, adreno-cortical insufficiency (Addison's disease, hypoaldosteronism), renal failure accompanied by oliguria or anuria and untreated diabetic ketosis; it i logically *decreased* by inadequate potassium intake or absorption, by digestive juices (diarrhoea, vomiting), and in adrenocortical hyperfi ing (hyperaldosteronism, Cushing's syndrome, corticosteroid thera ney disease accompanied by polyuria, medication with diuretic agen tubular acidosis, Fanconi's syndrome, and diabetic ketosis during treatment.

(For references see pages 567–568)

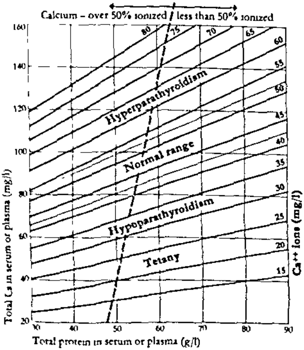
	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
odium (mEq/l)									
) Umbilical vein blood ...	...	...	..	...	146 8	131–163	8 1	10	Values from (a) 14, (b) 20, (c) 37, (d) 157, (e) 20, (f) 106, (g) 128 subjects by (a–d, f, g) flame photometry, (e) neutron activation. On the flame photometric method[59] and the effect of serum proteins on assay see the literature[62, 63].
) Newborn, 1 day	...	...	...	...	146 4	133–159	6 5	10	
) Newborn, 2 days.......	...	...	..	...	148.7	140–157	4 3	10	
		Erythrocytes							
) Adults	16 4	10–22	3 0	66	144 5	138–151	3 3	66	
) Adults	8 7	5 1–13 1	–	15	143.1	136–151	3.8	15	
l) Adults	...	. .	..	...	138	132–144	3	13	
) Adults	...	...	...	...	142 6	138–148	2 45	62	
) Adults	...	...	...	..	138.4	132–145	3.07	127	
g) (mEq/kg)...	10.9	8.3–13 5	1.3	127					
		Thrombocytes							
n) (mEq/kg)	27 0	25–28	–	55					

he sodium content of the erythrocytes is rather low during pregnancy[17]. The

The serum sodium level is pathologically *increased* in dehydration, sodium intoxication (for infants particularly a danger), adrenocortical hyperfunction-

agents, and diabetic ketosis

	Whole blood				Plasma or serum				Remarks
Calcium (mEq/l)									
(a) Cord blood				.	5 5	–	–	65	Values from (a) 3, (b) 48, (d) 70, (e) 21, (f) 35, (g) 50 subjects by (a, d, e, f) EDTA titration, (b) oxalate precipitation, (c, g) flame photometry. The oxalate-precipitation and flame photometric methods give rather higher values than EDTA titration[67, 69]. On the flame photometric method see MacIntyre[70, 71]
(b) Adults . ..					5 09	4 7–5 5	0 22	66	
(c) Adults .					5.2	4 8–5 6	0 2	67	
(d) 16–59 years .				.	4 74	4.56–4 92	0 09	129	
(e) 60–70 years ..					4.60	4 36–4 84	0 12	129	
(f) Adults .					4 9	4 6–5 2	0 13	68	
Protein-bound					1.8	1 4–2.2	0 18	68	
Ionized					2 9	2.7–3 1	0.10	68	
Complex					0.1	0–0 3	0 10	68	
		Erythrocytes							
(g) (mEq/kg).	0.12	0 05–0 19	0 034	3					



The serum calcium ... 35 50% ...

	Whole blood: Mean	Whole blood: 95% range (extreme range in brackets)	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range (extreme range in brackets)	Plasma or serum: s	Plasma or serum: Reference	Remarks
Magnesium (mEq/l)		Erythrocytes:							
(a) Cord blood	4.4	–	–	65	1.64	–	–	65	Values from (a) 3, (b) 77, (c, er cytes) 54, (c, serum) 46, (d) 40, ((f) 100, (g) 58, (h) 97 subjects by EDTA titration, (c, h) titanium y method, (d) ammonium phosphat cipitation, (e) emission flame p metry, (f, i, k) absorption flame p metry, (g) fluorometrically with droxyquinoline. On the emission photometric method see MACINTY
(b) Adults	5.3	4.24–6.36	0.53	65	2.00	1.70–2.30	0.15	65	
(c) Adults	4.78	3.30–6.26	0.74	76	1.70	1.30–2.10	0.20	76	
(d) Adults	4.93	3.87–5.99	0.53	76	1.73	1.45–2.01	0.14	76	
(e) Adults	...	...	...	...	1.66	1.50–1.82	0.08	77	
(f) Adults	...	...	...	...	1.74	1.52–1.96	0.11	78	
(g) Adults	...	...	...	...	1.89	1.6–2.2	–	79	
(h) Adults	...	...	...	...	1.80	1.28–2.32	0.26	80	
(i) Before puberty	3.76	(2.86–4.30)	–	83	1.69	(1.50–1.99)	–	83	
(k) After puberty	4.26	(3.68–5.26)	–	83	1.65	(1.36–2.07)	–	83	

For discussion of the discrepancies in the serum magnesium values see the literature[81]. The serum magnesium is about 30% protein-bound, 55–60% ionized and 10–15% in the form of complexes[25, 82]. The serum magnesium level is lower in the newborn and their mothers than in adults[65]. No age or sex differences have been observed in adults[78]. There is an extensive literature on magnesium metabolism[76, 77, 84, 85].
The serum magnesium is pathologically *increased* in kidney disease (the erythrocyte magnesium is also increased) and hypothyroidism; it is pathologi *decreased* in disturbances of magnesium absorption, severe vomiting diarrhoea, hyperparathyroidism, thyrotoxicosis, chronic alcoholism, pri aldosteronism and renal tubular acidosis, and occasionally in liver cirrh Serum magnesium levels below 1.3 mEq/l are marked by acute convulsio but the peripheral muscle cramps seen in hypocalcaemia do not occur.

	Whole blood: Mean	Whole blood: 95% range	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range	Plasma or serum: s	Plasma or serum: Reference	Remarks
Cobalt (μg/l)	0.35	–	–	86	0.29	–	–	87	
Iron (mg/l)									
(a) Cord blood	...	...	...	...	1.93	–	–	88	Serum values from (a) 21, (b) 17, (c) (d) 161, (e) 33 subjects by (a, b, e) col metry with *o*-phenanthroline[93], (c, dipyridyl method[92]. Serum iron also be determined with bathoph anthroline[94].
(b) Children, 3–10 years	...	...	...	...	0.86	0.20–1.52	0.33	88	
(c) Boys, 12–19 years	...	...	...	...	0.946	0.19–1.70	0.376	89	
(d) Girls, 12–19 years	...	...	...	...	0.917	0.25–1.59	0.335	89	
(e) Men	–	(440–560)	–	90	1.34	0.58–2.10	0.38	88	
(f) Women	–	(420–480)	–	90					
(g) Adults	...	...	...	...	–	0.75–1.75	–	91	
Total iron-binding capacity (= latent or unsaturated iron-binding capacity + serum iron) (mg/l)									
(b) Children, 3–10 years	...	...	...	...	4.0	(1.9–4.5)	–	88	
(g) Adults	...	...	...	...	–	2.5–4.0	–	92	

Most of the iron in the blood is contained in the haemoglobin of the erythrocytes; haemoglobin contains 0.347% iron. The serum iron is in the ferric form and is almost completely contained in the protein transferrin.
Serum iron. There are wide diurnal fluctuations[95], with values 10–30% higher in the morning than in the evening. In women the values are 10–15% lower than in men[92] and vary during the menstrual cycle[96]. In pregnant women approaching term the serum iron is 35% lower than in nonpregnant women[97]. In the newborn the level is at first high but falls rapidly during the first 12 hours[88]; it rises again during the first month, falls during the 2nd to 6th mont and often remains low up to the age of 2 years before rising to the adult le at school age[98]. On iron metabolism see the literature[92, 99].
The serum iron is pathologically *increased* in haemolytic anaemia, untreat pernicious anaemia, acute hepatitis and idiopathic haemochromatosis, path logically *decreased* in iron-deficiency anaemia, infections, the nephrotic sy drome and chronic bleeding.

	Whole blood: Mean	Whole blood: 95% range	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range	Plasma or serum: s	Plasma or serum: Reference	Remarks
Copper (mg/l)		Erythrocytes:							
(a) Cord blood	1.03	–	–	100	0.51	–	–	88	Erythrocyte values from (a) 3, (d, e) subjects; serum values from (a) 22, (17, (c) 31, (d) 120, (e) 85 subjects. A values determined colorimetrically wi dithizone. Copper can also be dete mined with bathocuproine[94] or oxal dihydrazide[102].
(b) Children, 3–10 years	...	...	...	...	1.31	0.77–1.85 (0.99–1.58)	0.27	88	
(c) Men	...	...	...	...	0.92	0.50–1.34	0.21	88	
(d) Men	0.89	0.72–1.06	0.085	100	1.10	0.79–1.41	0.157	101	
(e) Women	0.89	0.64–1.14	0.127	100	1.20	0.84–1.56	0.178	101	

Some 60% of the erythrocyte copper is contained in the erythrocuprein, 94% of the serum copper in the caeruloplasmin; both these proteins contain 0.32–0.36% copper. The copper content of the erythrocytes is much more constant than that of the serum, and there is no correlation between the two.
Serum copper. There may be wide fluctuations up to 0.3 mg/l from day to day[103]. During pregnancy the level rises by about 100% and then falls within two weeks post partum to the nonpregnancy level[100]. In the newborn it is much lower than in the mother because of the inability of caeruloplasmin to pass the placental barrier. The level rises steeply during the first year and is significantly higher in children than in adults[104]. There is an extensive literature on copp metabolism[105].
The serum copper is pathologically *increased* in infections, lupus erythematode glomerulonephritis, myocardial infarction, haemochromatosis, cirrhosis various organs, HODGKIN's disease, acute leukaemia, aplastic anaemia an thyrotoxicosis, as well as during oestrogen therapy; it is pathologica *decreased* in disturbances of copper absorption, kwashiorkor, hepatolenticula degeneration, idiopathic hypoproteinaemia and loss of caeruloplasmin in th kidneys (in the nephrotic syndrome). In hepatolenticular degeneration th copper not bound to caeruloplasmin is increased.

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
nganese (µg/l)									
....	–	(8 6–16.5)	–	106	–	(1 8–3 1)	–	106	Values (a) by neutron activation, (b) by colorimetry.
....	~200	Erythrocytes –	–	107	~100	–	–	107	
lybdenum (µg/kg) ..	3 3	0–8 3	2.5	36	. .	..	.	..	Values from 5 subjects by neutron activation
nc (mg/l)		Erythrocytes							
Cord blood	3 76	1.56–5.96	1.10	108	1 25	0 59–1.91	0.33	108	Values for whole blood and cells from (a) 32, (b) 16, (c) 12, (d) 84, (e) 27, (f, g) 29 subjects, for serum from (a) 39, (b) 15, (c) 11, (d) 126, (e) 40 subjects; values (e, whole blood) determined by neutron activation, all others colorimetrically About 35% of the serum zinc is bound to proteins During pregnancy the serum zinc level falls by about 20%[108 111] but that of the erythrocytes and leucocytes remains fairly constant[112] There is a considerable literature on zinc metabolism[113] The serum zinc is pathologically *decreased* in atrophic cirrhosis of the liver, infections, myocardial infarction and untreated pernicious anaemia The zinc content of the leucocytes is pathologically *decreased* in leukaemia[109 112] and cirrhosis of the liver[112 114].
Children, 4–11 months	7.77	4 37–11.17	1.70	108	1 27	0 69–1.85	0.29	108	
Children, 1–5 years ...	10.55	7.51–13 59	1.52	108	1 30	0.66–1.94	0.32	108	
Adults	12 44	8 84–16 04	1 80	108	1 09	0.69–1.49	0 20	108	
. .. . ..	5 9	Whole blood 3 7–8.1	1.1	109	1 21	0 83–1.59	0.19	110	
(mg/10¹² cells). . .	0 97	Erythrocytes 0 65–1.29	0 16	109					
) (mg/10¹² cells). . .	14 0	Leucocytes 0–34 8 (3 7–43.5)	10 4	109					
luminium (µg/l)	140	0–380	120	116	172	156–188	8	116	Serum values from 536 subjects No *dependence on age or sex has been observed*
rsenic (µg/l)	–	(60–200)	–	117					Values (a) from 8 subjects by neutron activation.
) (µg/kg)	4	0–10	3 1	36					
ead (µg/l)									
a)	270	170–370	50	118	29	–	–	115	Values (b) from 100 adults (90% of the values under 100 µg/l), values (a) determined spectrographically, (b, c) colorimetrically Most of the blood lead is in the erythrocytes[115] Whole-blood values exceeding 400 µg/l indicate an abnormally high lead absorption[118].
b)	–	(0–200)	–	118					
c)	–	(<300–400)	–	119					
Lithium (µg/l)				.	–	(3–44)	–	120	
Selenium (µg/kg)	120	20–220	50	36			.	.	Values from 6 subjects by neutron activation
Other elements					.	.	.	.	For a detailed list of the elements so far determined in blood see BOWEN[121] Recent assays have been made of barium[122 123], cadmium[124], chromium[123–125], gold[36], mercury[126], rubidium[123] and tin[115].

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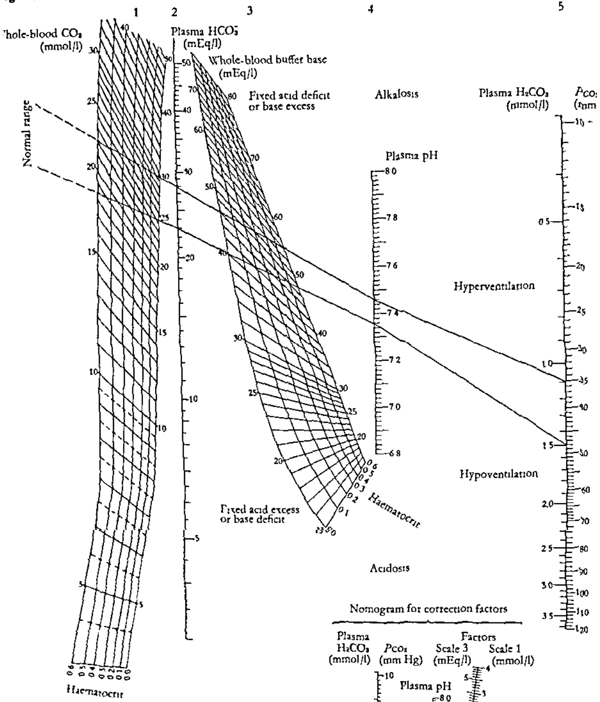
Blood gases (for blood pH values see page 560; for references see page 571)

The normal values given in the table on pages 570 and 571 are for sea level and can be used at altitudes up to 200 m without adjustment. In persons resident at high altitudes the value of P_{CO_2} is reduced as a result of chronic hyperventilation while the pH remains normal owing to complete renal compensation, so that the plasma bicarbonate concentration is also reduced (cf. 'Water and Electrolyte Balance', page 527).

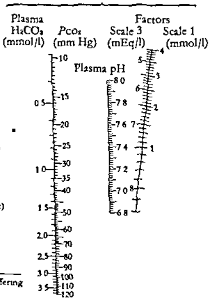
Blood samples for gas analysis must be drawn under anaerobic conditions. Even when they are stored under anaerobic conditions, however, it must be borne in mind that changes due to clotting, glycolysis, autoxidation and sedimentation will occur. Blood from the peripheral subcutaneous veins is not usually suitable for gas analysis. Venous mixed blood is drawn from the pulmonary arteries. Arterial blood should be drawn from the femoral, brachial or radial arteries. For the micro methods, capillary blood obtained by puncture of the warmed finger tip or of the lobe of the ear is su since its gas content is almost identical with that of arterial bl It has recently been recommended[2] that blood gas values be measured at 37 °C instead of 38 °C, or converted to the f temperature.

Methods[3–5]. Carbon dioxide, oxygen, nitrogen and carbon oxide are usually determined manometrically by VAN SLYKE's m or the KOPP-NATELSON micro modification of this method. C dioxide and oxygen can also be measured by mass spectrograp gas chromatography, oxygen capacity and oxygen saturati spectrophotometry, bicarbonate by titration, oxygen pres larographically, carbon dioxide pressure potentiometrically. ponents of the CO_2-bicarbonate system not measured directly obtained by calculation using the dissociation equilibrium of c ic acid (page 527) or by means of nomograms (pages 528 and

ogram for the acid-base balance of human blood at 37 °C (from SINGER and HASTINGS, *Medicine [Baltimore]*, 27, 223 [1948



Nomogram for correction factors



A straight line through points given on two of the scales ... [illegible]

$$(\text{whole-blood } CO_2)_{corrected} = \text{whole blood } CO_2 + (f_{scale\,1} \times U \times Ht)$$

$$(\text{whole-blood buffer base})_{corrected} = \text{whole blood buffer base} - (f_{scale\,3} \times U \times Ht)$$

$$Ht = \text{haematocrit} = \frac{\text{vol\% of erythrocytes in whole blood}}{100}$$

$$U = 1 - \frac{O_2 \text{ saturation in \%}}{100}$$

By whole-blood buffer base is understood the base equivalent of the sum of the buffering anions (bicarbonate, haemoglobin, plasma proteinate)

	Source of sample (blood unless otherwise stated)	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Oxygen								
Oxygen pressure (mm Hg)	Umbilical artery	Polarographic	25	9.2	0–19.2	5.0	6	Partial pressure of oxygen in a gaseous phase in equilibrium with blood (symbol P_{O_2} or p_{O_2}).
	Umbilical vein	Polarographic	25	22.4	12.8–32.0	4.8	6	
	Children, 1–4 weeks, arterial	Polarographic	12	85.6	70.7–101	7.45	7	
	Children, 4–16 months, arterial	Polarographic	13	78.0	55.0–101	11.51	7	
	Men, < 30 years, arterial	Polarographic	28	91.0	74.4–108	8.3	8	
	Men, > 60 years, arterial	Polarographic	10	79.7	62.7–96.7	8.5	8	
Oxygen content (vol%)	Umbilical artery	Manometric (VAN SLYKE)	25	2.9	0–6.9	2.0	6	Oxygen content of blood drawn and tested under exclusion of air. About 99% is bound to haemoglobin, the remainder in physical solution (for details see ALBRITTON[13]).
	Umbilical artery	Gas chromatographic	29	4.1	(0.4–7.7)	–	9	
	Umbilical vein	Manometric (VAN SLYKE)	25	10.6	4.2–17.0	3.2	6	
	Umbilical vein	Gas chromatographic	32	12.3	(6.2–16.6)	–	9	
	Children, 3–11 years, arterial	Manometric (VAN SLYKE)	9	15.6	13.7–17.5	0.93	10	
	Men, arterial	Manometric (VAN SLYKE)	50	19.6	17.2–22.0	1.2	11	
	Men, venous	Manometric (VAN SLYKE)	50	12.9	10.3–15.5	1.3	11	
Oxygen capacity (vol%)	Umbilical artery	Manometric (VAN SLYKE)	25	22.15	17.9–26.4	2.11	6	Oxygen content of blood saturated with oxygen (maximum content possible). The O_2 in physical solution is often ignored and the oxygen capacity equated with the amount capable of being bound by the haemoglobin, from the content of which it is then calculated.
	Children, 1–4 weeks, arterial	Manometric (VAN SLYKE)	12	20.38	14.5–26.2	2.93	7	
	Children, 4–16 months, arterial	Manometric (VAN SLYKE)	13	13.89	10.3–17.5	1.78	7	
	Men, arterial	Manometric (VAN SLYKE)	50	20.9	18.3–23.5	1.3	11	
	Men, venous	Manometric (VAN SLYKE)	50	20.8	18.2–23.4	1.3	11	
Oxygen saturation (%)	Umbilical artery	Manometric (VAN SLYKE)	25	13.7	0–32.1	9.2	6	Percentage saturation of the haemoglobin with oxygen (100 × O_2 content/O_2 capacity).
	Umbilical vein	Manometric (VAN SLYKE)	25	47.7	19.5–75.9	14.1	6	
	Children, 1–4 weeks, arterial	Manometric (VAN SLYKE)	12	95.2	89.0–101	3.11	7	
	Children, 4–16 months, arterial	Manometric (VAN SLYKE)	13	92.5	86.0–99.0	3.23	7	
	Men, arterial	Manometric (VAN SLYKE)	50	93.9	91.9–95.9	1.0	11	
	Men, venous	Manometric (VAN SLYKE)	50	61.8	54.4–69.2	3.7	11	
	Adults, capillary	Spectrophotometric	40	96.6	94.2–99.0	1.2	4	
Carbon dioxide								
Carbon dioxide pressure (mm Hg)	Umbilical artery	Calculated	25	60.4	43.2–77.6	8.6	6	Partial pressure of carbon dioxide in a gaseous phase in equilibrium with blood (symbol P_{CO_2} or p_{CO_2}).
	Umbilical vein	Calculated	25	44.9	28.9–60.9	8.0	6	
	Children, 1–4 weeks, arterial	Calculated	12	36.7	28.5–44.9	4.08	7	
	Children, 4–16 months, arterial	Calculated	13	32.1	24.6–39.6	3.77	7	
	Children, 2–12 months, capillary	Calculated	10	32.8	28.7–36.9	2.05	12	
	Adults, arterial	Calculated	15	37.5	33.0–42.0	2.23	14	
	Men, < 30 years, arterial	Potentiometric	24	39.3	31.9–46.7	3.7	8	
	Men, > 60 years, arterial	Potentiometric	11	38.8	32.5–45.1	3.16	8	
	Men, arterial	Calculated	50	39.9	36.3–43.5	1.8	11	
	Men, venous	Calculated	50	49.9	46.1–53.7	1.9	11	
	Men, capillary (38 °C)	Calculated	20	41.2	35.8–46.6	2.7	4	
	Women, capillary (38 °C)	Calculated	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Carbon dioxide content (mmol/l)	Umbilical artery	Manometric (VAN SLYKE)	25	21.4	17.0–25.8	2.2	4	Amount of CO_2 extractable by strong acid from blood drawn and tested under exclusion of air. In plasma about 5% is in physical solution, 94% as bicarbonate and 1% as carbamino compounds; in the erythrocytes the corresponding figures are 7%, 82% and 11% (for details see ALBRITTON[13]). The proportion of carbonic acid (H_2CO_3) and carbonate (CO_3^-) is very small. To convert the values given into vol% multiply by 2.226.
	Umbilical artery	Gas chromatographic	29	19.8	(13.3–25.6)	–	9	
	Umbilical vein	Manometric (VAN SLYKE)	25	18.3	13.9–22.7	2.2	4	
	Umbilical vein	Gas chromatographic	32	17.0	(11.1–21.2)	–	9	
	Children, 3–11 years, arterial	Manometric (VAN SLYKE)	9	20.4	18.2–22.6	1.1	10	
	Men, arterial	Manometric (VAN SLYKE)	50	21.6	20.4–22.8	0.6	11	
	Men, venous	Manometric (VAN SLYKE)	50	24.6	23.2–26.0	0.7	11	
	Adults, arterial (plasma)	Manometric (VAN SLYKE)	15	26.1	22.4–29.8	1.83	14	
	Men, arterial (plasma)	Manometric (VAN SLYKE)	50	26.6	24.6–28.6	0.99	6	
	Women, arterial (plasma)	Manometric (VAN SLYKE)	50	25.6	22.7–28.5	1.43	6	
	Men, venous (plasma)	Manometric (KOPP-NATELSON)	7	30.3	27.7–32.9	1.31	15	
	Women, venous (plasma)	Manometric (KOPP-NATELSON)	8	27.8	24.9–30.7	1.45	15	
Bicarbonate content (mEq/l)	Adults (plasma)	Titrimetric	–	–	21–30	–	16	The bicarbonate content of the plasma is usually calculated from the carbon dioxide content by subtracting the physically dissolved CO_2, but not the carbamino CO_2, from the total carbon dioxide. The values so obtained agree fairly well with those measured by titration.
	Adults, arterial (plasma)	Calculated	15	24.9	21.3–28.5	1.79	14	
	Adults (erythrocytes)	Calculated	9	11.2	10.9–11.5	0.15	17	
Standard bicarbonate (mEq/l)	Umbilical vein	Calculated	–	16.6	11.8–21.4	–	18	Bicarbonate content of the plasma of whole blood containing oxygen-saturated haemoglobin and equilibrated at a P_{CO_2} of 40 mm Hg at 37 °C. The standard bicarbonate can also be obtained from nomograms[4, 5]. The alkali reserve (carbon dioxide combining power) is the CO_2 content of the anaerobically separated plasma equilibrated at a P_{CO_2} of 40 mm Hg at room temperature; the values obtained are not absolutely reproducible.
	Children, 1–4 weeks, arterial (plasma)	Calculated	12	21.1	17.8–24.4	1.67	7	
	Children, 4–16 months, arterial (plasma)	Calculated	13	21.0	19.0–23.0	0.99	7	
	Adults, arterial (plasma)	Manometric (VAN SLYKE)	15	25.2	22.4–28.0	1.40	14	
	Men, capillary (plasma)	Calculated	20	–	22.1–25.8	–	5	
	Women, capillary (plasma)	Calculated	20	–	21.3–25.0	–	5	
Base excess (mEq/l)	Umbilical artery	Calculated	16	−9.9	–	–	9	Base concentration as measured by titration with strong acid up to pH 7.40 at a P_{CO_2} of 40 mm Hg (at 37 °C). Negative values are those measured by titration with a strong base (also called base deficit). For a Hb content of 150 g/l blood the following approximate relationship holds between the deviation of the standard bicarbonate from normal and the base excess: Δ standard bicarbonate × 1.2 = base excess
	Umbilical vein	Calculated	16	−6.4	–	–	9	
	Umbilical vein	Calculated	–	−9.5	−16.6 to −2.5	–	18	
	Men, capillary	Calculated	20	−0.1	−2.4 to 2.3	–	4	
	Women, capillary	Calculated	20	−1.0	−3.3 to 1.2	–	4	
Buffer base (mEq/l)	Umbilical vein	Calculated	–	37.2	30.8–43.7	–	18	Sum of the basic buffer anions in whole blood, namely bicarbonate, haemoglobin and plasma proteinate. Obtained by use of the nomogram on page 569
	Men, arterial	Calculated	153	48.4	46–52	–	19	
	Men, capillary	Calculated	180	50.1	47–53	–	19	
	Women, capillary	Calculated	24	48.0	45–51	–	19	

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(For references see page 578)

	Whole blood: Mean	Whole blood: 95% range (extreme range in brackets)	Whole blood: *s*	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range (extreme range in brackets)	Plasma or serum: *s*	Plasma or serum: Reference	Remarks
Total nitrogen (g/l)	34.3	(30.0–41.0)	–	1	13.1	(12.0–14.3)	–	1	Comprises the chemically bound gen. Because of the fibrinogen th nitrogen of the plasma is slightly than the serum value given here. F KJELDAHL method of N determi see ARCHIBALD et al.[6]. The prop of protein N in the total N is ove in the erythrocytes, over 96% i serum, about 80% in the leucocyt about 90% in the thrombocytes; erythrocytes 94% of the total N i tained in the haemoglobin.
		Erythrocytes:							
(g/l)	–	(57–62)	–	2					
(g/kg)	55.3	51.7–58.9	1.8	3					
(mg/10^9 cells)	4.61	3.77–5.45	0.42	4					
		Leucocytes:							
	10.0	0–23.8	6.9	4					
		Thrombocytes:							
	–	(0.31–0.39)	–	5					
Nonprotein nitrogen (NPN) (mg/l)									
(a) Cord blood	311	244–378	33.4	7	...	...	...	...	Values from (a) 25, (b) 21, (c) 25, ((e) 58, (f) 46 subjects by (a–d) m of FOLIN[9], (e, f) method of RAPPAPO On a high-protein diet the NPN co is increased and the proportion of N is up to 90%; on a low-protei the NPN content is reduced an proportion of urea N is 50% or le Towards the end of pregnancy the content of the blood decreases an proportion of urea N is small[11]. NPN is pathologically *increased* in ous kidney diseases, obstruction o urinary tract, burns and shock, *de* in severe liver damage. See also u 'Urea', below, and page 531.
(b) Newborn, 5–6 days	266	201–331	32.3	7					
(c) Children, 1–6 years	324	253–395	35.7	7					
(d) Adults	331	219–443	56.0	7					
(e) Men	276	202–350	36.9	8	249	177–321	35.9	8	
(f) Women	261	183–339	39.1	8	223	139–307	42.0	8	
		Erythrocytes:							
(e) Men	309	211–407	48.9	8					
(f) Women	318	189–447	64.7	8					
Urea (mg/l)									
(a) Cord blood	294	148–440	73	12	216	158–274	29	7	Values from (a, whole blood) 13 serum) 25, (b) 21, (c) 25, (d) 30, (e (f) 31, (g) 10 subjects by cleavage urease and determination of NH NESSLER's reagent[14] or better BER LOT's reagent[15,16]. In an auton series of assays using diacetylmo ime[17] 90% of the values were b 200 mg/l serum. For calculation of urea content from the NPN see page The urea content of the blood dep mainly on the protein intake, the am of urine excreted and the functi state of the kidneys. The concentra in the cord blood is determined by in the maternal blood[12]; in preg women it appears to be rather low[7]. urea content is *increased* when pro breakdown in organs is increased instance in fever and after operatio in disturbances of renal excretion an obstruction of the urinary tract; i *decreased* frequently in dehydrated tients given N-free solutions[18].
(a) Newborn, 3 hours	257	71–443	93	12					
(a) Newborn, 24 hours	318	60–576	129	12					
(b) Newborn, 5–6 days	...	...	...	...	201	139–263	31	7	
(c) Children, 1–6 years	...	...	...	...	313	241–385	36	7	
(d) Adults	...	...	...	...	328	230–426	49	7	
(e) Men	272	156–388	58	8	305	177–433	64	8	
(f) Women	241	131–351	55	8	238	122–354	58	8	
		Erythrocytes:							
(e) Men	232	114–350	59	8					
(f) Women	178	58–298	60	8					
(g) In relation to protein intake									
0.5 g protein/kg body weight/day	...	...	...	...	193	135–251	29	13	
1.5 g protein/kg body weight/day	...	...	...	...	386	244–528	71	13	
2.5 g protein/kg body weight/day	...	...	...	...	455	311–599	72	13	
Creatine (mg/l)									
Children, 1–14 weeks	...	...	...	...	–	(2.2–12.5)	–	19	Serum values by (a) JAFFÉ reaction, fluorometry with ninhydrin. On JAFFÉ reaction see below under 'Cr tinine'. The serum creatine level is so what increased on a diet rich in meat.
Adults									
(a)	27	–	–	20	–	(1.6–4.0)	–	21	
(b)	...	...	...	...	–	(1.9–7.9)	–	22	
		Erythrocytes:							
	56.2	–	–	23					
Creatinine (mg/l)									
(a) Cord blood	...	...	...	...	11.8	6.4–17.2	2.7	7	Serum values from (a) 25, (b) 18, (c) (d) 30, (e) 39, (f) 28 subjects; values (e, by an automatic method. The JA reaction often used to determine c atine and creatinine is not specific is subject to interference by gluc acetoacetic acid, acetone, ascorbic ac pyruvate, etc. Values also depend how the sample is prepared; th measured by the enzymatic[25] and exchange[26] methods (true creatini are about 10–20% less than the JA reaction values. For further discuss of methods see the literature[21,27].
(b) Children, 4–21 weeks	...	...	...	...	9.5	7.9–11.1	0.8	7	
(c) Children, 1–6 years	...	...	...	...	11.9	7.5–16.3	2.2	7	
(d) Adults	6	–	–	20	12.4	6.6–18.2	2.9	7	
(e) Men	...	...	...	...	8.55	5.3–11.9	1.69	24	
(f) Women	...	...	...	...	7.12	5.6–8.6	0.77	24	
		Erythrocytes:							
	4.5	–	–	23					

The serum creatinine level is *increased* by ingestion of creatinine (for instance in roast meat); it is largely proportional to the muscle mass and therefore higher in men than in women (see also page 531). The level is pathologically *increased* when endogenous synthesis is increased (as in acromegaly) and when excretion is impaired.

Blood – Nitrogenous Substances

(For references see page 578)

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
uanidine (mg/l)	–	(<0 4)	–	20					
uanidinoacetic acid (mg/l)	–	(<3)	–	20	–	(2,4–4.4)	–	28	Absent from the erythrocytes[25].
lethylguanidine (mg/l)	–	(<0 2)	–	20					
mmonia (mg/l)									
ı) Newborn, 0–14 days	–	(0 9–1.5)	–	29	...	..	...	...	Values from (b, whole blood) 25, (b, serum) 30, (c) 20, (d) 50, (e) 25 subjects by (a, d, e) diffusion method, (b, c) ion-exchange chromatography. In the newborn the blood ammonia level is higher than in the mother[34], it is high in premature infants and newborn with icterus[29], very often also in patients with incipient hepatic coma[35].
ı) Children	–	(0.07–0.63)	–	29					
;) Adults	0 48	0 22–0 74	0.13	30	0.20	(0 04–0 33)	–	31	
:) Adults	..	...	...	...	0.19	0 08–0 30	0 055	32	
l) Adults, venous blood	1.02	0.56–1.48	0 23	33					
e) Adults, arterial blood	1 06	0.76–1.36	0.15	33					
'ree amino acids (as α-amino-N) (mg/l)									
a) Cord blood	.	.		.	76 8	36 8–116.8	20	36	Values from (a) 25, (b) 32, (c, d) 53 subjects by colorimetric method with ninhydrin. A measure of the amino-acid content is the α-amino-N content, best determined by the gasometric ninhydrin method[37], though this also measures the α-amino groups of peptides and other substances. In serum the α-amino-N value depends on the manner in which the proteins are precipitated[38], it is rather higher than in the plasma owing to release of amino acids from the thrombocytes during coagulation. (For individual amino acids in blood see page 574.)
b) Children, 6–11 years	.	.		..	50 1	24 1–76 1	13	36	
(c) Men	61	48 4–73.6	6 3	8	42	33 4–50 6	4 3	8	
(d) Women	59	48 2–69 8	5 4	8	39	28 0–50 0	5.5	8	
		Erythrocytes							
(c) Men	87	71 8–102.2	7 6	8					
(d) Women	90	75 0–105 0	7 5	8					
Carnitine (mg/l)					–	(8 6–13.3)	–	49	
Ergothioneine (mg/l)		Erythrocytes							
(a) Adults	96	34–158	31	50		.	...	..	Values from (a) 94 measurements and (b) 4, (c) 10, (d) 15, (e) 13 subjects. The blood level depends on the ergothioneine content of the diet. Pathological variations have been reported[50, 51].
(μmol/kg water)									
(b) Cord blood	162	26–298	68	45					
(c) Children, 4 days–1 year	125	17–233	54	46					
(d) Children, 1–12 years	200	0–410	105	46					
(e) Adults	458	90–826	184	41	–	(<10)	–	41	
	–	Leucocytes (<300)	–	41					
Glutathione (mg/l)									
(a) Adults	354	(269–414)	–	52	..	.	..	..	Values from (a) 10, (b) 102, (c) 10 subjects. Glutathione occurs only in the erythrocytes. In its reduced form it accounts for some 30% of the nonsugar reducing substances of whole blood. There appears to be a close relationship between glutathione stability and the sensitivity of the cells to haemolysis[44].
		Erythrocytes							
(b) Newborn, < 48 hours	782	748–816	16 9	53					
(b) Newborn, > 48 hours	697	662–732	17.6	53					
(c) Adults	–	(586–689)	–	54					
(μmol/10^{11} cells)									
Reduced (GSH)	210	144–276	33	55					
Oxidized (GSSG)	22	10–34	6	55					
Aliphatic amines (as N) (mg/l)	0.30	0 08–0.52	0 11	57	.	..	...	...	Values from 35 subjects. Ethanolamine and dimethylamine predominate.
Ethanolamine (μmol/kg water)	–	Erythrocytes (<10)	–	41	–	(<10)	–	41	For plasma values see also the table on page 574.
	–	Leucocytes (<250)	–	41					
Phosphoethanolamine (mg/l)									
Cord blood	.		...	..	2.7	0–5.5	1.4	41	
Maternal blood	.	.	...	...	0.5	0–1.1	0.3	41	
(μmol/kg water)	2651	Leucocytes 451–4851	1100	41					

(For references see page 578)

Amino acids

Individual amino acids can be determined by microbiological methods[39] or after separation by paper chromatography[40, 41] or column chromatography[42, 43]; for a few there are also specific chemical methods. STEIN and MOORE's column-chromatographic separation usually yields 26 amino acids in serum, with a further 6 ninhydrin-positive substances occurring in traces. Normal values are shown in the table below. For further data see the literature (reviews[43, 44], values in children[45, 46], cord-blood values[47]).

Physiological variations. The amino-acid content of the blood is increased for several hours after a protein-rich meal. It is higher in newborn and particularly premature infants than in older children; in children in general it is rather lower than in adults, though there are wide individual variations. Values for glutamic acic in children than in adults. In women the amino-acid coı blood shows some dependence on the menstrual cycle: of the luteal phase the alanine, serine, lysine, threonine : contents are low, while during pregnancy most amino ac sent in rather lower amount than in the luteal phase.

Pathological variations. The serum amino-acid content in liver disease, particularly acute yellow atrophy of the li burns and shock, in diabetes with ketosis and in k (especially β-aminobutyric acid), *decreased* somewhat in The contents of some amino acids are increased in her turbances of amino-acid metabolism (see pages 448–45(ther discussion of the pathological variations see the li

Free amino acids in the plasma and blood cells of newborn, children and adults (by ion-exchange column chromatogra

	Newborn* 1st day		Adults*		Children** 9 months–2 years		Adults†	Men††		
	Plasma		Plasma		Plasma		Plasma	Plasma[42]	Erythro-cytes	Leuco-cytes
	Mean	Range	Mean	Range	Mean	Range	Range	Mean		
	mg/l	mg/l	mg/l	mg/l	μmol/l	μmol/l	μmol/l	μmol/kg	μmol/kg	μmol/kg
Alanine	29.4	21.0–36.5	30.7	22.2–44.7	219	99–313	213–472	420	350	6610
β-Alanine	1.3	–	0.8	–	0	0	–	–	–	–
α-Aminobutyric acid	1.5	0.6–3.0	1.7	1.0–2.4	5	0–17	10–35	–	–	–
β-Aminoiso-butyric acid	–	–	–	–	5	0–22	trace	–	–	–
Arginine	9.4	3.8–15.3	14.3	8.6–26.3	31	11–65	40–140	100	0	330
Asparagine	6.0	–	5.7	–	–	–	–	–	–	–
Aspartic acid	1.1	trace–2.2	2.2	trace–7.2	2	0–9	1–11	2	370	3500
Citrulline	2.8	1.5–5.0	5.3	2.1–9.7	–	–	10–17	–	–	–
Cystine§	14.7	8.5–20.2	17.7	11.5–33.7	4	0–40	70–108	110	0	370
Ethanolamine	3.2	1.6–5.6	0.1	trace–0.7	–	–	–	–	–	–
Glutamic acid	7.6	3.0–15.7	8.6	2.5–17.3	–	–	(20–90)	(50)	(320)	(7360)
Glutamine	112	79–140	83	61–102	135	46–290	(140–570)	–	–	–
Glycine	25.8	16.8–38.6	17.4	10.8–36.6	170	56–308	179–587	220	370	5080
Histidine	11.9	7.6–17.7	12.4	9.7–14.5	64	24–112	32–97	80	140	630
Hydroxyproline	4.2	–	0.92 §§	0.69–1.20 §§	–	–	–	–	–	–
Isoleucine	5.2	3.5–6.9	7.1	4.6–11.5	44	26–94	40–99	70	40	2900
Leucine	9.5	6.1–14.3	13.2	9.3–17.8	75	45–155	78–176	140	400	6300
Lysine	29.3	16.7–39.3	25.4	21.1–30.9	87	45–144	105–207	200	130	2360
Methionine	4.4	1.3–6.1	3.2	2.3–3.9	21	3–29	11–30	30	trace	1750
1-Methylhistidine	–	–	–	–	0	0	0–10	–	–	–
3-Methylhistidine	–	–	–	–	0	0	0–8	–	–	–
Ornithine	12.1	6.5–20.0	9.2	4.3–16.7	40	10–107	30–64	–	–	–
Phenylalanine	13.0	6.9–18.2	9.5	6.3–19.2	40	23–69	38–73	50	40	2480
Proline	21.3	12.3–31.9	27.1	12.8–51.4	115	51–185	103–290	220	170	2100
Serine	17.2	9.9–25.5	11.8	6.8–20.3	92	24–172	76–164	120	150	5100
Taurine	17.6	9.3–27.0	8.3	5.7–17.3	49	19–91	32–138	50	36	26000
Threonine	25.9	13.6–39.9	19.4	12.2–29.3	60	33–128	76–194	130	160	3400
Tryptophan	6.5	trace–13.7	9.8	5.1–14.9	–	–	–	–	–	–
Tyrosine	12.6	7.6–18.0	9.1	6.5–11.3	45	11–122	22–83	60	50	1970
Valine	16.0	9.4–28.8	19.9	13.6–26.6	127	57–262	168–317	270	330	3750

* Values from 25 infants before the first feed and 8 adults[129].
** Fasting values from 20 children (VIS, H., quoted by SOUPART, P.[43]).
† Fasting values from 30 adults assembled from the literature[43].
†† Blood-cell values from one man[43].

§ Values in μmol are for cystine ½ + cysteine. The plasma of adul tains about 10 mg cystine and about 4 mg cysteine per litre[130].
§§ Fasting values from 10 men[131].

(For references see page 578)

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
[illegible]stamine (mg/l)	2.9	–	–	58					
[illegible]ermine (mg/l)	1.34	1.14–1.54	0 10	59	...	...	...	...	Values from 30 subjects. Both amines are found only in the cells
[illegible]ermidine (mg/l)	0 96	0 86–1 06	0 05	59	...	...	...	...	
[illegible]etylcholine (µg/l)	...	...	...	.	12.8	0–36 8 (3.2–48 0)	12.0	60	Values from 14 subjects. Higher in asthmatic patients.
[illegible]oline (mg/l)									
[illegible]tal choline	...				–	(244–542)	–	61	The serum choline is almost all in the form of phospholipids.
[illegible]e choline	.	.	.	.	4 4	(2.5–9 9)	–	62	
[illegible]techolamines	.				.	...	...	...	See pages 731 and 733.
[illegible]stamine (µg/l)	–	(16–89)	–	63	2.6	(0–15)	–	63	Histamine occurs mainly in the leucocytes[64] (values in µg per 10^9 cells) neutrophils 3.3, basophils 1080, eosinophils 160, lymphocytes 0 6, monocytes 1.2, thrombocytes 0 009. The blood histamine is increased in the carcinoid syndrome[65] and particularly in chronic myeloid leukaemia owing to the increased number of basophils[64].
[illegible]fotenine (µg/l)	–	(0–27)	–	66					
[illegible]yptamine	.						...	...	Tryptamine has been found in the blood of a patient with a carcinoid tumour[67].
[illegible],N-Dimethyltryptamine (µg/l)	39	27–51	6	68			...	...	Values from 50 subjects.
[illegible]rotonin (µg/l)	–	(90–180)	–	69	13	1–25	6	70	Most of the blood serotonin is adsorbed on the thrombocytes. It is increased in the carcinoid syndrome[72], with thrombocyte values up to 18.5 µg/10^9 cells[71].
[illegible]g/10^9 cells)	0 336	Thrombocytes 0 148–0 524	0 094	70					
	0 45	0 13–0 77	0 16	71					
Indoxylsulphuric acid (indican) (mg/l)									
[illegible]) Men					3	1.2–4 8	0.9	73	Values from (a) 56, (b) 44 subjects. The serum indican is increased in the nephrotic syndrome[74].
[illegible]) Women					3	0 6–5 4	1.2	73	
[illegible]Sulphatoxyskatole (mg/l)					–	(0–1)	–	75	
[illegible]dolyl-3-acetic acid (mg/l)					–	(1–2)	–	75	
[illegible]dolyl-3-lactic acid (mg/l)					–	(0 1–1)	–	76	
[illegible]orphyrins									
[illegible]-Aminolaevulinic acid (mg/l)	–	Erythrocytes (0 25–0 45)	–	76	0 19	0 11–0 27	0 04	77	Serum values from 50 men. Aminoacetone is also formed in the erythrocytes during the biosynthesis of δ-aminolaevulinic acid[78].
[illegible]orphobilinogen (mg/l)	–	Erythrocytes (0.15–0 40)	–	76					
[illegible]oproporphyrin (µg/l)									
[illegible]) Cord blood	28	Erythrocytes 0–60 (11–72)	16	79	15	1–29 (7–32)	7	79	Erythrocyte values from (a) 20, (b) 10, (c, d) 20 subjects, serum values from (a) 15, (c, d) 11 subjects. The coproporphyrin content of the erythrocytes shows good correlation with the reticulocyte count[79]. It is often markedly increased in congenital erythropoietic porphyria, [illegible], and [illegible], increased in [illegible], [illegible] increased in [illegible], while [illegible]
[illegible]) Newborn, 9–15 days	8	–	–	79					
[illegible]) Men	13	5–21 (7–23)	4	79	8	2–14 (4–15)	3	79	
[illegible]) Women	12	0–26 (3–23)	7	79					

(For references see page 578)

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Protoporphyrin (µg/l)		Erythrocytes:							
(a) Cord blood	540	40–1040 (320–1350)	250	79	...	...	...	...	Values from (a) 20, (b) 10, (20 subjects. Protoporphyrir absent from the serum[83]. Th phyrin content of the erythro so closely correlated with tl cyte count as the coproporp tent[80]. It is markedly increas ropoietic protoporphyria[81] deficiency anaemia, slightly ir haemolytic anaemia, shows values in *lead poisoning*, an within the normal limits in anaemia[80].
(b) Newborn, 9–15 days	510	–	–	79					
(c) Children, 1–2 years	320	–	–	79					
(d) Men	300	150–450 (160–520)	75	79					
(e) Women	370	170–570 (180–510)	100	79					
		Erythrocytes:							
Uroporphyrin (µg/l)	–	(0–20)	–	76					
Haemoglobin									
Cord blood (mg/l)	...	...	...	...	80	–	–	84	Values (a) from blood drawn puncture of the heel, (b) fro jects by the benzidine reactio rum haemoglobin is increas bodily activity and may reacl the normal value in highly-tr letes. The serum haemoglobir *to haptoglobin*; the maximur capacity is 1.4 g/l serum[87]. ' from 200 subjects. See also and 613.
(a) Newborn (mg/l)	...	...	...	...	–	(1000–1310)	–	84	
(b) Adults (mg/l)	...	...	...	...	3.1	(1.6–5.8)	–	85	
(c) Adults (g/l)	158.5	134–173	–	86					
		Erythrocytes:							
(c) Adults (g/l)	328	299–357	–	86					
Haemiglobin (methaemoglobin) (as % of the haemoglobin)	0.4	(0.0–1.1)	–	88	...	...	...	...	For spectrophotometric dete see HAINLINE et al.[90]. Clinicals (cyanosis) appear at 20% ar concentrations of haemiglobi there is danger to life at 70 toxic and congenital haemiglc (methaemoglobinaemia) see J HELLER[92].
	0.65	0.25–1.05	0.20	89					
Carboxyhaemoglobin (as % of the haemoglobin)									
(a) Newborn	0.42	0–1.54 (0.1–1.8)	0.56	93	...	...	...	...	Values (a) from 20 infants up old (infants with Rh and AB patibilities had values from 1.9 [93]), (b) measured in a CO-fr sphere, (c) measured in a norn sphere. Values of 12% and m been measured in car drivers. symptoms appear at 15–25%, c life at 65%[91].
(b) Adults	0.55	–	–	94					
(c) Adults	3.4	0–8.2	2.4	95					
Verdoglobin (mg/l)	4	–	–	96					
Bilirubin (mg/l)									
Direct-reacting									
(a) Adults	...	...	...	...	1.0	(0.5–2.4)	–	97	Values from (a, b) 110, (c) 49, (e) 11, (f) 10, (g) 11, (h) 6, (i) subjects. Determination by BERGH reaction; for modific MALLOY and EVELYN (denatur methanol) see MACDONALD et al that of JENDRASSIK and GROF (tion with acetate, benzoate and see GAMBINO et al.[102]. In the ne direct spectrophotometric met been used[15,103]. On methods in see the literature[15,104]; purity bilirubin standard is all-importa The direct-reacting bilirubin of reaction represents roughly t jugated bilirubin (bilirubin dig ide, smaller amounts of bilirubi glucuronide and sulphate), the d between the total bilirubin and reacting bilirubin (indirect b the free bilirubin. It is uncertain direct-reacting bilirubin is pr the serum of healthy persons.
Total									
(b) Adults	...	...	...	...	6.0	(2.6–14)	–	97	
(c) Premature infants, cord blood	...	...	...	...	18.5	2.9–34.1	7.8	98	
(d) Newborn, cord blood	...	...	...	...	15.1	1.7–28.5	6.7	98	
(e) Newborn, 1 day	...	...	...	...	26.8	0–60.0	16.6	99	
(f) Newborn, 3 days	...	...	...	...	58.5	2.5–114.5	28.0	99	
(g) Newborn, 5 days	...	...	...	...	60.6	1.0–120.2	29.8	99	
(h) Newborn, 7 days	...	...	...	...	50.0	1.4–98.6	24.3	99	
Free									
(i) Men	...	...	...	...	4.0	1.5–10.5	–	100	
(j) Women	...	...	...	...	2.8	1.1–7.0	–	100	

The free (unconjugated) bilirubin is normally bound to albumin, the binding capacity of which can be determined[106]. The bilirubin of pathological sera can be separated chromatographically into 4 fractions[107], namely free, monoconjugated, diconjugated and albumin-bound. On the physiology and pathology of bilirubin metabolism see the literature[108,109], also pages 363- the table on the opposite page.

Simple jaundice of infants. Owing to deficiency of UDP glucuronyl tra the liver is incapable of conjugating all the bilirubin present, so that th

iturbances of bilirubin metabolism

Type of jaundice	Nature of metabolic disturbance	Site	Free bilirubin in serum († increased)	Conjugated bilirubi in serum († increase
[illegible]	[illegible]	Reticular system	† † ††	(†) (†) –
[illegible]	[illegible] ides into the duodenum			
Iepatitis, cirrhosis	At several stages of bilirubin metabolism		†	††

	Whole blood: Mean	95% range (extreme range in brackets)	s	Reference	Plasma or serum: Mean	95% range (extreme range in brackets)	s	Reference	Remarks
rines, nucleotides									
lantoin (mg/l)					–	(3–6)	–	113	
ic acid (mg/l)									
Newborn, up to 4 days					55	–	–	114	Serum values from (a) 70, (b) 224, (c) 874, (d) 899 subjects by uricase method whole blood values from (c) 13, (d) subjects by chromatography, age rang of subjects (c, d) 4–88 years For discus sion of methods of uric acid determina tion see the literature[119]
) Children, 4–9 years					37 3	–	–	116	
) Males	23 6	16 0–31 2	3 8	116	48 6	20 8–76 4	13 9	115	
) Females	22 7	13 7–31 7	4 5	116	41 8	18 2–65 4	11 8	115	
		Erythrocytes							
	25	–	–	117					
[illegible]					The serum uric acid level is pathologically *increased* in gout, in renal injury, an when nucleic acid metabolism is increased (as for instance in myeloic leukaemi and polycythaemia), *decreased* in WILSON's disease and the FANCONI syndrom and by the administration of uricosuric drugs				
anthine and hypo-xanthine (mg/l)					–	(~1–2)	–	121	
ucleotides (μmol/l)									
denosine monophosphate	–	(2–14)	–	118					Values from 13 men and 8 women afte chromatographic separation. Nucleo tides are found only in the cells, and th plasma contains traces at most Variou nucleotides have been determined i whole blood and erythrocytes[124], leuco cytes[125] and thrombocytes[126]. A hered itary type of increased erythrocyte ATI content has been reported[127].
denosine diphosphate	–	(32–73)	–	118					
denosine triphosphate	–	(287–586)	–	118					
uanosine triphosphate	–	(13–36)	–	118					
osine triphosphate	3	–	–	123					
ridine diphosphate	4 5	–	–	123					
icotinamide-adenine dinucleotide	–	(22–40)	–	118					
As NAD	33 0	–	–	122					
As NADH₂	4 6	–	–	122					
icotinamide-adenine dinucleotide phosphate	–	(2–15)	–	118					
As NADP	11 6	–	–	122					
As NADPH₂	16 0	–	–	122					

(For references see page 578)

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Protoporphyrin (µg/l)		Erythrocytes:							
(a) Cord blood	540	40–1040 (320–1350)	250	79	...	...	...	...	Values from (a) 20, (b) 10, (c) 8, (d, e) 20 subjects. Protoporphyrin is almost absent from the serum[83]. The protoporphyrin content of the erythrocytes is not so closely correlated with the reticulocyte count as the coproporphyrin content[80]. It is markedly increased in erythropoietic protoporphyria[81] and iron-deficiency anaemia, slightly increased in haemolytic anaemia, shows very high values in lead poisoning, and remains within the normal limits in pernicious anaemia[80].
(b) Newborn, 9–15 days	510	–	–	79					
(c) Children, 1–2 years	320	–	–	79					
(d) Men	300	150–450 (160–520)	75	79					
(e) Women	370	170–570 (180–510)	100	79					
Uroporphyrin (µg/l)	–	Erythrocytes: (0–20)	–	76					
Haemoglobin									
Cord blood (mg/l)	...	...	...	...	80	–	–	84	Values (a) from blood drawn by careful puncture of the heel, (b) from 25 subjects by the benzidine reaction. The serum haemoglobin is increased during bodily activity and may reach 30 times the normal value in highly-trained athletes. The serum haemoglobin is bound to haptoglobin; the maximum binding capacity is 1.4 g/l serum[87]. Values (c) from 200 subjects. See also pages 611 and 613.
(a) Newborn (mg/l)	...	...	...	...	–	(1000–1310)	–	84	
(b) Adults (mg/l)	...	...	...	...	3.1	(1.6–5.8)	–	85	
(c) Adults (g/l)	158.5	134–173	–	86					
(c) Adults (g/l)	328	Erythrocytes: 299–357	–	86					
Haemiglobin (methaemoglobin) (as % of the haemoglobin)	0.4	(0.0–1.1)	–	88	...	...	...	...	For spectrophotometric determination see Haining et al.[90]. Clinical symptoms (cyanosis) appear at 20% and higher concentrations of haemiglobin[91], and there is danger to life at 70%[92]. On toxic and congenital haemiglobinaemia (methaemoglobinaemia) see Jaffé and Heller[92].
	0.65	0.25–1.05	0.20	89					
Carboxyhaemoglobin (as % of the haemoglobin)									
(a) Newborn	0.42	0–1.54 (0.1–1.8)	0.56	93	...	...	...	...	Values (a) from 20 infants up to 4 days old (infants with Rh and AB0 incompatibilities had values from 1.9 to 11.9%[93]), (b) measured in a CO-free atmosphere, (c) measured in a normal atmosphere. Values of 12% and more have been measured in car drivers. Clinical symptoms appear at 15–25%, danger to life at 65%[91].
(b) Adults	0.55	–	–	94					
(c) Adults	3.4	0–8.2	2.4	95					
Verdoglobin (mg/l)	4	–	–	96					
Bilirubin (mg/l)									
Direct-reacting									
(a) Adults	...	...	...	...	1.0	(0.5–2.4)	–	97	Values from (a, b) 110, (c) 49, (d) 150, (e) 11, (f) 10, (g) 11, (h) 6, (i) 61, (j) 53 subjects. Determination by van den Bergh reaction; for modification of Malloy and Evelyn (denaturing with methanol) see MacDonald et al.[101], for that of Jendrassik and Grof (acceleration with acetate, benzoate and caffeine) see Gambino et al.[102]. In the newborn a direct spectrophotometric method has been used[15,103]. On methods in general see the literature[15,104]; purity of the bilirubin standard is all-important[15,105]. The direct-reacting bilirubin of the diazo reaction represents roughly the conjugated bilirubin (bilirubin diglucuronide, smaller amounts of bilirubin monoglucuronide and sulphate), the difference between the total bilirubin and direct-reacting bilirubin (indirect bilirubin) the free bilirubin. It is uncertain whether direct-reacting bilirubin is present in the serum of healthy persons.
Total									
(b) Adults	...	...	...	...	6.0	(2.6–14)	–	97	
(c) Premature infants, cord blood	...	...	...	...	18.5	2.9–34.1	7.8	98	
(d) Newborn, cord blood	...	...	...	...	15.1	1.7–28.5	6.7	98	
(e) Newborn, 1 day	...	...	...	...	26.8	0–60.0	16.6	99	
(f) Newborn, 3 days	...	...	...	...	58.5	2.5–114.5	28.0	99	
(g) Newborn, 5 days	...	...	...	...	60.6	1.0–120.2	29.8	99	
(h) Newborn, 7 days	...	...	...	...	50.0	1.4–98.6	24.3	99	
Free									
(i) Men	...	...	...	...	4.0	1.5–10.5	–	100	
(j) Women	...	...	...	...	2.8	1.1–7.0	–	100	

The free (unconjugated) bilirubin is normally bound to albumin, the binding capacity of which can be determined[106]. The bilirubin of pathological sera can be separated chromatographically into 4 fractions[107], namely free, monoconjugated, diconjugated and albumin-bound. On the physiology and pathology of bilirubin metabolism see the literature[108,109], also pages 363–364 and the table on the opposite page.

Simple jaundice of infants. Owing to deficiency of UDP glucuronyl transferase the liver is incapable of conjugating all the bilirubin present, so that the serum

.rubin increases About 40% of newborn infants have a serum .f over 40 mg/l during the first week[110]. The bilirubin level is nbilical arterial serum than in the umbilical venous serum[111], *lice of the newborn*. With increasing haemoglobin breakdown the ı level rises, as soon as the binding capacity of the albumin is exceeded, kernicterus may develop Exchange transfusions are recommended when the serum bilirubin exceeds 190–250 mg/l, depending on the age and health of the child For further discussion of haemolytic jaundice and kernicterus see the literature[98 109 112]

:a of bilirubin metabolism

ype of jaundice	Nature of metabolic disturbance	Site	Free bilirubin in serum (↑ increased)	Conjugated bilirubin in serum (↑ increased)
. . . .	. . .	Reticular system	↑ ↑ ↑↑	(↑) (↑) –
. haemolytic jaundice . T's syndrome) c hyperbilirubinaemia .	Impaired transport of free bilirubin	Liver (lysosomes)	↑ ↑	– –
ndice of infants . . . . ıl jaundice) NAJJAR syndrome . .	Incomplete conjugation of free bilirubin	Liver (microsomes)	↑ ↑↑	– –
: jaundice . HNSON syndrome . . ıdrome . .	Impaired excretion of bilirubin glucuronides	Bile capillaries	(↑) (↑) ↑	↑ ↑ ↑
ve jaundice .	Impaired transport of bilirubin glucuronides into the duodenum	Bile ducts	(↑)	↑↑
cirrhosis . .	At several stages of bilirubin metabolism		↑	↑↑

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
leotides									
(mg/l).					–	(3–6)	–	113	
(mg/l)									
rn, up to 4 days					55	–	–	114	Serum values from (a) 70, (b) 224, (c) 874, (d) 899 subjects by uricase method, whole-blood values from (c) 13, (d) 8 subjects by chromatography, age range of subjects (c, d) 4–88 years For discussion of methods of uric acid determination see the literature[118].
n, 4–9 years .					37 3	–	–	115	
.	23 6	16 0–31 2	3 8	116	48 6	20 8–76 4	13 9	115	
s	22 7	13.7–31 7	4 5	116	41 8	18 2–65 4	11 8	115	
		Erythrocytes							
	25	–	–	117					

re acid level is *high in the newborn, in children rather lower* than men it remains fairly constant throughout life, in women it is the menopause than in men, higher after it The upper limit of uricase method) is 75 mg/l serum in men, 60 mg/l serum in women [19] There is an extensive literature on uric acid metabolism[120].

The serum uric acid level is pathologically *increased* in gout, in renal injury, and when nucleic acid metabolism is increased (as for instance in myeloic leukaemia and polycythaemia), *decreased* in WILSON's disease and the FANCONI syndrome and by the administration of uricosuric drugs

and hypo- e (mg/l)					–	(~1–2)	–	121	
les (μmol/l)									
: monophosphate	–	(2–14)	–	118					Values from 13 men and 8 women after chromatographic separation Nucleotides are found only in the cells, and the plasma contains traces at most. Various nucleotides have been determined in whole blood and erythrocytes[124], leucocytes[125] and thrombocytes[126] A hereditary type of increased erythrocyte ATP content has been reported[127].
: diphosphate	–	(32–73)	–	118					
: triphosphate	–	(287–586)	–	118					
: triphosphate	–	(13–36)	–	118					
phosphate	3	–	–	123					
phosphate	4 5	–	–	123					
ude-adenine otide	–	(22–40)	–	118					
D	33 0	–	–	122					
DH₂	4 6	–	–	122					
nide-adenine otide phosphate	–	(2–15)	–	118					

	Whole blood				Plasma or serum				Remarks
	Mean	95% range	s	Reference	Mean	95% range	s	Reference	
Nucleic acids (mg/10^9 cells)		Leucocytes:							
Ribonucleic acid	8.19	0.91–15.47	3.64	128					
Deoxyribonucleic acid	6.86	4.52–9.20	1.17	128					

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	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Total proteins (g/l)	–	180–210	–	1	–	Serum 65–80	–	1	In whole blood the haemoglobin of the erythrocytes predominates It makes up about 94% of the erythrocyte protein, the remainder consisting of stroma albumin, free globin and various enzymes. For data on the haemoglobin content see page 617 The proteins of the erythrocytes[4] and leucocytes[5] can be separated by electrophoresis On the plasma proteins see below and pages 580–583
	–	Erythrocytes 330–390	–	1					
(mg/10⁹ cells)	100	Leucocytes –	–	2					
	–	Thrombocytes (1.6–1.8)	–	3					
Fibrinogen (g/l)	..	.	...		2 95	Plasma 2 6–3 3 (2 0–4 0)	0.17	6	Values from 20 subjects Occurs also in the thrombocytes[7].

Plasma proteins[8, 9]

method), ultracentrifuging, chromatography on ion-exchangers, gel filtration or various methods of electrophoresis (method of TISELIUS or using filter paper, starch gel, agar gel, cellulose acetate foil, etc , as carrier) Individual proteins can be identified by im-

whereby up to 30 different serum protein fractions can be separated Enzymes can be determined by means of their biochemical activity (see page 584). For the simple separation of the albumins from the globulins by salting out see REINHOLD et al [11] With the exception of erythrocyte sedimentation (see pages 558–559), serum lability reactions are no longer used

Physiological variations Procedural differences make it desirable

and composition occur particularly during the first year of life[9, 13] (see page 583) and in pregnancy[14] (see page 691) The adult plasma protein level is reached at the age of about 3 years[13] In old age the albumin content falls while the β-globulin content rises[15] (see page 582) Differences in the plasma protein level between whites and negroes have often been observed[16].

Several of the serum proteins exhibit allotypy (see under 'Serum Groups', page 634)

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Metabolism of the plasma proteins[1]

	Amount (g/kg body weight)	Synthesized in	Half-life (days)	Breakdown (% per day)	Breakdown (site)
Albumin	1 1–1 7	Liver	~15	5–8	Gastrointestinal tract
γ-Globulins	0 54	Plasma cells	γG 23 γA 6 γM 5	3 12 14	Liver, gastrointestinal tract
α- and β Globulins	–	Liver	~ 5	–	Liver? Gut?
Fibrinogen	0 7–0 8	Liver	~ 5	–	–

[1] For detailed discussion see WUHRMANN and MÄRKI, *Dysproteinämien und Paraproteinämien*, Schwabe, Basle, 1963 ANKER, H S., in PUTNAM, F W (Ed), *The Plasma Proteins* vol 2, Academic Press, New York, 1960, page 267 Data on the immunoglobulins from FAHEY, J L , *J Amer med Ass* , 194, 255 (1965)

Physicochemical and biological characteristics of defined plasma proteins[1]
(For lipoproteins see page 602, for glycoproteins see page 606)

	Grammes per 100 g plasma proteins (%)	Iso-electric point (pH)	Electro-phoretic mobility* (10^{-5} cm² V^{-1} s^{-1})	Sedimentation constant S_{20w} (10^{-13} cm² s^{-1} dyn^{-1})	Diffusion constant D_{20w} (10^{-7} cm² s^{-1})	Approximate molecular weight	Fu
Prealbumin (tryptophan-rich)	0.1–0.5	–	9.0	4.2	–	61 000	Thyro: bindin
Albumin..................	50–65	4.9	5.9	4.6	5.9	69 000	Colloi pressu and re: protei
Acid α_1-glycoprotein (α_1-seromucoid, orosomucoid)	0.5–1.5	2.7	5.1	3.1	5.3	44 100	Tissue down] (?)
α_1-Antitrypsin.............	1.9–4.0	–	–	3.4	–	45 000	Inhibit trypsin
α_2-Macroglobulin.........	1.5–4.5	5.4	4.2	19.4	2.4	900 000	Inhibit protein
α_2-Haptoglobin............	0.3–1.9	4.1	3.3	4.1	4.7	85 000	Haemo binding
α_2-Caeruloplasmin	0.3–0.5	4.4	4.6	7.2	4.7	150 000	Oxidas (?); co content
β_1-Siderophilin (transferrin) .	3.0–6.5	5.8	3.1	6.1	6.2	88 000	Iron tra defence infectio
α_1-Lipoprotein							
density 1.093	4.5–8	–	–	5.5	–	435 000	Lipid tr
density 1.149				5.0	–	195 000	
α_2-Lipoprotein	0.5–1.5	–	–	$S_f>12$	–	3 400 000	Lipid tr
β_1-Lipoprotein	4–14	5.4	3.1	$S_f=0$–12	–	2 500 000	Lipid tr
γA, IgA (β_{2A}-globulin, γ_{1A}-globulin)............	0.8–2.8	–	−2.2	7 (10, 13, 15, 17)	–	180 000–500 000	
γM, IgM (β_{2M}-globulin, γ_{1M}-globulin, γ_1-macroglobulin, 19 S γ)..	0.6–1.7	–	−2	18–20	–	950 000	Immunc lins: car of specit humoral bodies***
γG, IgG (γ-globulin, γ_2-globulin, γ_{ss}-globulin, 7 S γ)..................	13–22	7.3	−0.8	6.5–7	4.0	150 000	
γD, IgD..................	<0.5	–	–	6–7	–	150 000 (?)	
γE, IgE**	<0.002	–	–	8	–	200 000	
Fibrinogen................	2.5–5.0	5.4	2.1	8.5	2.0	340 000	Coagula

* pH 8.6; ionic strength 0.1.
** Identical with IgND.

[1] From summaries in Hitzig, W.H., *Die Plasmaproteine in der klinischen Medizin*, Springer, Berlin, 1963, page 45; Phelps and Putnam, in Putnam, F.W. (Ed.), *The Plasma Proteins*, vol. 1, Academic Press, New York, 1960, page 143; Wuhrmann and Märki, *Dysproteinämien und Paraproteinämien*, Schwabe, Basle, 1963, page 55; Schwick and Störiko, *Laboratoriums-* ... Behringwerke AG., Marburg-Lahn,

*** Some of the antibodies in this group are:
γA Various insulin antibodies, tetanus antitoxin, polio *I/III* ar certain isoagglutinins
γM Isoantibodies anti-A and anti-B, agglutinating Rh antibodie and nonspecific cold-agglutinins, heterophilic agglutinins, MANN antibodies, antinuclear antibodies, rheumatoid facto tinins (properdin)
γG Incomplete Rh antibodies, incomplete antibodies anti-A an LE-factor (?), blocking antibodies
γD Nature unknown

:ture of the immunoglobulins[1]

:ains* . . . . { H	γ		α		δ		ε		μ		–	–
L	κ	λ	κ	λ	κ	λ	κ	λ	κ	λ	κ	λ
olecular type	K	L	K	L	K	L	K	L	K	L	K	L
ɿain combination	$\kappa_2\gamma_2$	$\lambda_2\gamma_2$	$[\kappa_2\alpha_2]_n$	$[\lambda_2\alpha_2]_n$	$\kappa_2\delta_2$	$\lambda_2\delta_2$	$\kappa_2\varepsilon_2$	$\lambda_2\varepsilon_2$	$[\kappa_2\mu_2]_n$	$[\lambda_2\mu_2]_n$	κ_2	λ_2
			$n = 1, 2, 3$						$n = 5$			
ormal immunoglobulin	γG-Globulin		γA-Globulin		γD-Globulin		γE-Globulin		γM-Globulin		γU-Globulin	
:raprotein**	Myeloma globulins								Macroglobulin		BENCE-JONES globulin	

** Paraproteins are proteins of abnormal structure in the immunoglobulin group appearing in neoplastic diseases of the reticuloendothelial system

[1] HEIDE, K., in *Die gelben Hefte*, Immunbiologische Informationen der Beh-[illegible]

ɿino-acid and carbohydrate composition of human serum proteins (g/100 g protein)[1]

	Pre-albumin	Albumin	Acid α_1-glycoprotein	α_1-Anti-trypsin	Hapto-globin	Caerulo-plasmin	α_2-Macro-globulin	Trans-ferrin	γG-Globulin	γM-Globulin	γA-Globulin
Lysine	6.96	10.95	4.48	7.15	8.17	5.84	5.34	9.65	6.96	4.88	4.57
Histidine	3.62	3.17	1.12	2.92	3.12	3.93	2.70	3.33	2.28	1.83	1.93
Ammonia	1.00	0.94	1.49	1.04	1.40	1.40	1.37	1.23	1.46	1.23	2.02
Arginine	4.27	5.38	3.44	1.85	2.23	4.38	3.82	5.15	4.02	5.05	4.55
Aspartic acid	6.44	9.05	5.72	8.02	9.53	9.45	7.16	11.40	7.69	7.12	6.15
Threonine	9.17	4.31	4.02	4.97	4.42	5.35	5.35	3.71	7.18	7.23	7.65
Serine	7.36	3.15	1.44	2.98	3.50	3.64	5.50	4.38	9.69	6.95	7.93
Glutamic acid	10.91	15.85	10.50	10.90	9.70	10.88	12.30	10.22	11.26	10.62	10.52
Proline	5.31	3.65	1.81	2.69	4.19	3.21	4.07	3.82	6.05	5.27	6.26
Glycine	3.94	1.05	1.03	2.03	2.90	2.98	2.75	3.44	3.35	3.06	3.22
Alanine	6.25	6.67	1.52	2.89	3.53	2.44	3.44	5.00	3.18	3.51	3.87
Cystine ½	0	5.09	0.68	0	2.05	0.72	1.14	5.07	2.20	1.58	2.10
Valine	8.44	6.17	2.14	3.86	6.25	4.10	6.80	5.40	8.10	6.49	6.00
Methionine	0.86	1.08	0.37	1.66	1.04	1.98	1.53	1.31	0.85	1.16	0.80
Isoleucine	3.68	1.31	2.46	3.32	3.38	4.13	3.09	2.10	2.14	2.70	1.74
Leucine	5.50	10.30	3.92	8.25	6.03	5.51	7.76	8.21	7.21	6.33	7.76
Tyrosine	5.51	4.03	4.08	1.87	5.55	7.55	4.84	4.61	5.97	4.21	4.38
Phenylalanine	5.11	6.74	3.31	6.37	2.36	5.07	5.37	5.07	4.29	3.96	3.66
Tryptophan	2.40	0.13	1.40	0.55	2.60	2.30	1.30	2.10	3.83	2.80	3.30
Sum	96.73	99.02	54.93	73.32	81.95	84.86	85.63	95.20	97.71	85.98	88.41
Hexoses	0.4	0.05	14.70	4.70	7.80	3.00	3.6	2.40	1.10	5.40	3.20
Acetylhexosamine	0.1	0.03	13.90	3.90	5.30	2.40	2.9	2.00	1.30	4.40	2.90
Acetylneuraminic acid	0	0	12.10	3.60	5.30	2.40	1.8	1.40	0.30	1.30	1.80
Fucose	0	0	0.70	0.20	0.20	0.18	0.1	0.07	0.20	0.70	0.22
Sum	97.23	99.10	96.33	85.72	100.55	92.84	94.03	101.07	100.61	97.78	96.53

[1] HEIMBURGER et al., *Clin. chim. Acta*, 10 293 (1964)

Serum and plasma protein fractions of adults

Free electrophoresis of serum and plasma proteins[1]

	Serum (30 subjects)						Plasma (7 subjects)		
	Absolute values (g/l serum)			Relative values (g/100 g total protein)			Absolute values (g/l plasma)	Relative values (g/100 g total protein)	
	Mean	Extreme range	s	Mean	Extreme range	s	Extreme range	Mean	Extreme range
Total protein	73	68–82	3.7	100	–	–	~69–85	100	–
Albumin	46.2	42.2–53.9	2.9	63.5	59.7–68.6	2.32	–	61.2	57.0–65.8
Globulins	26.8	22.5–31.0	2.2	36.5	31.4–40.3	2.32	–	38.8	32.2–43.0
α-Globulin	6.8	5.1–9.8	1.1	9.2	7.0–12.2	1.43	–	9.2	8.1–10.5
α_1-Globulin	–	–	–	2.0	1.1–3.0	0.52	–	–	–
α_2-Globulin	–	–	–	7.3	5.5–9.8	1.15	–	–	–
β-Globulin	8.2	5.5–10.1	1.1	11.3	7.7–14.0	1.40	–	11.5	10.5–12.9
γ-Globulin	11.6	8.8–15.0	1.4	15.9	12.3–18.9	1.6	–	14.1	12.7–17.0
Fibrinogen	–	–	–	–	–	–	~2–4	4.0	2.2–5.8
Albumin: globulin ratio	–	–	–	1.74	1.49–2.19	0.17	–	1.59	1.32–1.92

[1] Riva, G., *Das Serumeiweißbild*, 2nd ed., Huber, Berne, 1960, page 257.

Electrophoresis of serum proteins on paper[1] *or cellulose acetate*[2]

	Paper electrophoresis (12 subjects)			Electrophoresis on cellulose acetate (40 subjects)			
	Relative values (g/100 g total protein)			Absolute values (g/l serum)		Relative values (g/100 g total protein)	
	Mean	Extreme range	s	Mean	95% range	Mean	95% range
Total protein	100	–	–	75.0	66–84	100	–
Albumin	65.2	58.0–71.9	4.35	44.7	37–52	59.6	52.2–67.0
Globulins	34.8	28.1–42.0	4.35	–	–	–	–
α-Globulin	10.9	8.4–14.2	2.0	–	–	–	–
α_1-Globulin	4.1	3.1–6.6	1.14	2.5	1–4	3.5	2.4–4.6
α_2-Globulin	6.7	5.2–9.1	1.28	7.5	5–10	10.1	6.6–13.6
β-Globulin	9.8	6.1–12.0	1.64	9.0	6–12	11.9	9.1–14.7
γ-Globulin	14.1	10.3–18.4	2.92	11.1	6–16	14.8	9.0–20.6
Fibrinogen	–	–	–	–	–	–	–
Albumin: globulin ratio	1.92	1.42–2.59	0.38	–	–	1.48	–

[1] Riva, G., *Das Serumeiweißbild*, 2nd ed., Huber, Berne, 1960, page 257.
[2] Kaplan and Savory, *Clin. Chem.*, 11, 937 (1965).

Serum proteins of men at various ages (g/l)[1]

	Number	Total protein		Albumin		α_1-Globulin		α_2-Globulin		β-Globulin		γ-Globulin	
		Mean	95% range	Mean	95% range	Mean	95% range	Mean	95% range	Mean	95% range	Mean	95% range
18–36 years	22	71.9	62.1–81.7	38.1	29.9–46.3	3.7	2.3–5.4	7.6	3.8–11.3	9.9	6.7–17	12.5	7.3–17
65–92 years	43	69.3	58.4–89.2	32.7	26.9–38.5	3.8	2.4–5.2	8.8	5.8–11.8	11.3	8.7–13.9	13.0	6.6–19.4

[1] Paper electrophoresis values from National Institute of Mental Health, Bethesda, Maryland, in Birren et al. (Eds.), *Human Aging*, Public Health Service Publication No. 986, U.S. Department of Health, Education and Welfare, Bethesda, 1963, page 37.

m proteins at various ages (g/l)

	Reference	Total protein	Albumin*	α_1-Globulins*	α_1-Lipoprotein**	α_2-Globulins*	α_2-Macroglobulin**	α_2-Haptoglobin***	α_2-Caeruloplasmin†	β-Globulins*	β_1-Lipoprotein**	β_1-Siderophilin††	γA-Globulin**	γM-Globulin**	γG-Globulin††
		Mean (s in brackets)													
laternal blood	1	59.31 (3.54)	27.46 (3.00)	3.97 (0.71)	2.36 (2.24)	7.30 (1.45)	4.33 (1.45)	1.44 (0.69)	0.89 (0.27)	10.85 (1.26)	4.89 (1.93)	4.80 (0.64)	1.05 –	0.96 (0.46)	10.9 (0.8)
ord blood... .	1	54.81 (3.24)	32.16 (3.38)	2.31 (0.31)	0.28 (0.22)	4.51 (0.58)	4.54 (1.44)	0.26 (0.38)	0.11 (0.06)	4.66 (0.86)	1.16 (0.47)	3.33 (0.24)	<0.02 –	<0.09 –	12.5 (2.0)
hildren															
0–14 days . ..	1	51.30 (5.10)	30.06 (3.64)	2.33 (0.39)	0.65 (0.27)	4.89 (0.62)	5.17 (1.12)	0.15 (0.07)	0.17 (0.05)	4.32 (0.79)	2.50 (0.74)	2.70 (0.09)	<0.02 –	0.22 (0.06)	9.9 (0.8)
2–4 weeks .	1	50.78 (3.74)	29.71 (3.54)	2.59 (0.66)	0.40 (0.17)	4.86 (1.16)	4.55 (2.70)	0.41 (0.37)	0.20 (0.08)	5.01 (0.75)	1.38 (0.43)	2.74 (0.26)	0.09 (0.12)	0.27 (0.09)	9.5 (0.6)
5–9 weeks ..	1	53.37 (3.04)	35.10 (2.64)	2.60 (0.48)	0.33 (0.15)	5.13 (0.82)	3.60 (1.70)	0.25 (0.24)	0.24 (0.06)	5.25 (0.61)	1.42 (0.46)	3.03 (0.23)	0.45 (0.25)	0.26 (0.11)	6.3 (1.8)
2–6 months	1	56.50 (3.98)	35.02 (2.78)	2.01 (0.72)	0.61 (0.31)	6.78 (1.15)	5.44 (1.81)	0.73 (0.41)	0.25 (0.11)	6.75 (1.27)	2.36 (1.03)	3.59 (0.35)	0.50 (0.20)	0.35 (0.13)	5.8 (1.2)
6–13 months	1	60.56 (3.31)	36.09 (2.63)	2.19 (0.61)	0.89 (0.39)	7.55 (1.37)	5.60 (2.01)	1.17 (0.57)	0.39 (0.17)	7.81 (0.82)	3.26 (1.03)	3.94 (0.38)	0.69 (0.27)	0.55 (0.23)	7.5 (1.3)
1¼–3 years	2	64.40 (4.31)	36.20 (3.39)	3.26 (0.72)	– –	8.15 (1.27)	5.00 (1.41)	0.95 (0.46)	0.51 (0.09)	8.92 (1.38)	4.60 (1.71)	3.53 (0.41)	– –	0.67 (0.36)	8.66 (2.42)
3–7 years	2	66.90 (4.56)	36.58 (2.59)	3.40 (0.65)	– –	7.59 (1.08)	4.72 (1.27)	0.68 (0.32)	0.51 (0.12)	8.89 (0.23)	4.22 (1.73)	3.53 (0.44)	– –	0.64 (0.18)	13.00 (2.81)
7–11 years	2	68.86 (2.64)	37.96 (2.60)	3.15 (0.53)	– –	7.15 (1.18)	4.50 (1.50)	0.61 (0.41)	0.44 (0.14)	8.78 (1.50)	4.12 (1.66)	3.57 (0.56)	– –	0.61 (0.25)	14.20 (2.71)
11–16 years .	2	69.17 (2.79)	37.50 (2.11)	3.32 (0.56)	– –	6.81 (0.96)	3.46 (0.87)	0.47 (0.30)	0.41 (0.11)	8.94 (1.56)	3.78 (1.48)	3.41 (0.37)	– –	0.55 (0.25)	13.85 (1.83)
Adults	2	69.86 (1.43)	36.58 (2.81)	3.11 (0.41)	– –	6.76 (1.27)	2.92 (0.98)	0.81 (0.46)	0.38 (0.08)	8.74 (1.07)	3.56 (1.90)	3.00 (0.38)	– –	0.68 (0.29)	13.14 (2.02)
Adults	7	69.25 (1.86)	35.75 (2.11)	3.58 (0.54)	0.80 (0.16)	7.08 [illegible]	3.56 [illegible]	1.10 [illegible]	0.32 [illegible]	8.66 [illegible]	2.18 [illegible]	3.66 [illegible]	0.80	0.66 [illegible]	11.7 [illegible]

Blood – Enzymes*

(For references see pages 588–589)

Enzymes are proteins with particular catalytic functions. They are identifiable and measurable by their activity, i.e., their ability to transform a particular substrate. The greater the rate at which the substrate is transformed, the higher the activity of the enzyme. For further discussion of enzyme kinetics see the section on pages 382–386, in which this and other aspects of enzymes (notably nomenclature, specificity and structure) are dealt with.

Enzyme units. At the present time a large number of enzyme units are in use, a situation that makes it difficult to compare the values from different laboratories even when the same method is used. For this reason the International Union of Biochemistry (IUB)[1] has recommended the use of a standard unit (U)** defined as follows:
1 U of any enzyme is that amount which will catalyse the transformation of 1 μmol of the substrate per minute under standard conditions.

The usual multiples kU, mU, μU, etc. are used. The recommended standard conditions are 30 °C (formerly 25 °C) and, if possible, optimal pH and substrate concentration. The IUB has also defined a number of other quantities in terms of the unit of enzyme:

Enzyme concentration:	U/ml solution (U/l solution, U/kg tissue and U/g tissue are also in use)
Specific activity:	U/mg enzyme preparation
Molecular activity:	U/μmol enzyme

Table 1 gives factors for converting some of the units at present in use into U/l (≡ mU/ml) (temperature differences have not been allowed for), while Table 2 lists temperature correction factors for some important enzymes.

About 90% of the total cell protein consists of enzymes. The various organs and tissues are equipped with a specific set of enzymes depending on their particular function. The differences between these sets of enzymes are mainly of a quantitative nature[2], and the function of an organ or tissue derives from its possession of an enzyme pattern in which important elements are not single enzymes but 'constant-proportion' groups of enzymes[3]. The enzymes involved in the principal energy-supplying metabolic reactions constitute a basic pattern that is complemented by other, variable enzymes. Depending on the metabolic type of the tissue concerned, the relationship of the latter – for instance lactate dehydrogenase, α-glycerophosphate dehydrogenase or the enzymes of the hexose monophosphate cycle – to the basic metabolic pattern is very variable. Their activity may differ by several orders of magnitude from one organ to another.

The variable enzymes of organs, especially the parenchymatous organs, naturally include all those that are carriers of specific organ properties. With some of these the differences in activity from organ to organ are so large that the description of 'organ-specific' or 'tissue-specific' enzyme is justified, examples being the 'liver enzymes' iditol dehydrogenase and ketose-1-phosphate aldolase and the 'muscle enzyme' creatine kinase. With the aid of these enzymes and the differing relationships between the ubiquitous metabolic enzymes it is possible to recognize the enzyme pattern peculiar to an organ from a very small part of it; this may be as little as 3–4 enzymes if these are suitably chosen[4].

'Isozyme'[5] (or 'isoenzyme') is the term given to enzymes having the same catalytic function but different structures and therefore different properties[6]. The fact that the proportions of the total activity of an enzyme attributable to its various isoenzymes differ markedly from one organ to another presents a further means of distinguishing between the enzymatic equipment of different organs. The best-known example is provided by the enzyme lactate dehydrogenase[7], whose isozyme distribution in the heart differs considerably from that in the liver. A large number of enzymes are known to possess isozymes, among them malate dehydrogenase aspartate aminotransferase[9,10], isocitrate dehydrogenase[9,11], [illegible]cose-6-phosphate dehydrogenase[11], glycerophosphate dehy[illegible]genase[11], phosphopyruvate hydratase[12], leucinaminopeptidas[illegible] alkaline phosphatase[14,15], acid phosphatase[14,16], cholinesteras[illegible] ribonuclease[18], [illegible][19], phosphogluconate [illegible]hydrogenase[20], [illegible] kinase[22], phospho[illegible]comutase[23] and amylase[24].

Within the cell the enzymes are located in various compartme[illegible] namely the cytoplasm, mitochondria, lysosomes, microsomes [illegible] nucleus, and are classified into types I and II. Type I enzymes easily extractable and probably only loosely bound to the hy[illegible]

Table 1 Conversion factors for some enzyme units

To convert from the unit given to the standard unit (U/l by the factor. The normal ranges given in the literature fo differ according to the method of measurement used (inde of the unit chosen).

Unit given	Conversic
*1. NAD/NADP-dependent reactions**	
Method of BÜCHER[131] 25 °C, $E^{366}_{0.100}$/100 s × 1 ml	18.3
Method of KARMEN and WRÓBLEWSKI[132] 23 °C, $E^{340}_{0.001}$/1 min × 3 ml	0.4
Method of AMELUNG and HORN[101] 25 °C, 1 μmol/1 h × 1 ml	16.7
Method of HOLZER and GERLACH[133] 24 °C, $E^{366}_{0.001}$/1 min × 3 ml	0.9
2. Fructosediphosphate aldolase	
Method of BRUNS[134] 37 °C, 1 μl fructose-1,6-diphosphate solution/1 h × 1 ml	0.61
Method of SIBLEY and LEHNINGER[135] 38 °C, 1 μl fructose solution/30 min × 0.04 ml	0.74
Method of SCHAPIRA[136] 37 °C, 1 mg triosephosphate-P/1 min × 1000 ml	16.00
3. Alkaline phosphatase	
KING-ARMSTRONG method[137,138] 37.5 °C, 1 mg phenol/15 min × 100 ml	7.1
Method of SHINOWARA[139] 37 °C, 1 mg P/1 h × 100 ml	5.4
BESSEY-LOWRY method (also for acid phosphatase)[140] 38 °C, 1 mmol *p*-nitrophenol/1 h × 1000 ml	16.7
Method of BODANSKY (also for acid phosphatase)[141] 37.5 °C, 1 mg P/1 h × 100 ml	5.4
4. Acid phosphatase	
KING-ARMSTRONG method[137] 37.5 °C, 1 mg phenol/1 h × 100 ml	1.8
5. Amylase (diastase)	
Method of SOMOGYI[142] 37 °C, 5 mg starch/15 min × 100 ml	20.6
Method of WOHLGEMUTH[143] 38 °C, 1 mg starch/30 min × 1 ml	206.0

* The units of activity are expressed as the decrease (subscript) in optic density (or extinction, E) at the given wave length (superscript) over t[illegible] given time and light path.

* The data on pages 584–600 have been compiled in conjunction with E. SCHMIDT and F. W. SCHMIDT, *Gastroenterological Department*, Medical Clinic, Medizinische Hochschule, Hannover. The enzymes are referred to throughout by the trivial names recommended by the Enzyme Commission (EC) of the International Union of Biochemistry (see page 385). In particular, the trivial names aspartate aminotransferase for the former glutamate-oxalacetate transaminase and alanine aminotransferase for the former glutamate-pyruvate transaminase should be noted.

** Also known as the International Unit (IU). The International Union of Pure and Applied Chemistry and the International Federation for Clinical Chemistry have jointly recommended the enzyme unit catal (catalytic amount; symbol cat) defined as follows[1a]:
1 cat = the catalytic amount of a system which catalyses as many cycles per second of a stated reaction scheme as there are atoms in 0.012 kg of the pure nuclide ^{12}C. It follows that 1 U = 16.67 ncat (n = nano).

(For references see pages 588–58')

Table 2 Correction factors for conversion of activity values to 25°C

Temperature of measurement	Lactate dehydrogenase[144]	Alanine aminotransferase[144]	Aspartate aminotransferase[144]	Malate dehydrogenase[33]	Glucose-6-phosphate dehydrogenase and phosphogluconate dehydrogenase[33]	Cholinesterase[33]
20 °C	1.470	1 400	1.390	1 520	1.300	1.360
21 °C	1.350	1 310	1.300	1.390	1.240	1 280
22 °C	1.250	1.220	1.220	1.280	1.180	1 200
23 °C	1.160	1.140	1.150	1.180	1 120	1 120
24 °C	1.080	1 060	1 070	1 090	1 060	1.055
25 °C	1 000	1 000	1.000	1 000	1.000	1 000
26 °C	0 928	0 930	0.936	0 920	0 950	0 950
27 °C	0 862	0 874	0 878	0 860	0.900	0 900
28 °C	0 802	0 817	0 821	0 800	0 850	0 855
29 °C	0.742	0 767	0.770	0 740	0.800	0 815
30 °C	0 694	0.716	0.719	0 680	0 760	0 775
31 °C	0.640	0 672	0.675	0 630	0.720	0.740
32 °C	0.598	0.628	0 636	0 580	0 680	0.700
33 °C	0 556	0 591	0.599	0.540	0 650	0.670
34 °C	0 520	0 553	0 560	0 500	0 620	0 635
35 °C	0 485	0 516	0.528	0.460	0 590	0 605
36 °C	0 449	0 484	0 497	0 430	0 560	0 575
37 °C	0 419	0 459	0 465	0 400	0 530	0.545

plasm, like lactate dehydrogenase and alanine aminotransferase, whereas type II enzymes are released only when the cell is severely disrupted, like the ...

increased release of enzymes during muscular work is more important[27].

Physiological variations in enzyme activity (see also the main table on pages 590–600)

The concentrations of the various enzymes in the body fluids have lognormal rather than normal distributions; for this reason the data in the main table do not include the usual 95% range calculated from the mean and standard deviation.

transferase[31] and creatine kinase[32]. For almost all the diagnostically useful enzymes, however, men and women can be assumed to have the same normal limits[33 34].

Age differences. Many enzymes have higher serum values in the immediate postnatal period and early infancy In the 2nd to 3rd

age[36], though these are probably a result of the increased incidence of subclinical ailments

Daily variations Data on diurnal changes in serum enzyme levels are conflicting Fluctuations of up to 40% (though with very wide

Table 3 Enzyme activities (in U/g tissue[4 145] or U/10¹¹ cells[146])

Tissue	Hexokinase	Iditol dehydrogenase	Ketose-1-phosphate aldolase	Fructosediphosphate aldolase	Glycerophosphate dehydrogenase	Alcohol dehydrogenase	Glyceraldehydephosphate dehydrogenase	Phosphopyruvate hydratase	Pyruvate kinase	Lactate dehydrogenase	Malate dehydrogenase	Isocitrate dehydrogenase	Glutamate dehydrogenase	Aspartate aminotransferase	Alanine aminotransferase	Glucose-6-phosphate dehydrogenase	Phosphogluconate dehydrogenase	Phosphoglycerate kinase	Phosphoglycerate phosphomutase
Liver	25 2	71 9	3 4	5 7	14 8	30 5	75 2	22.2	15 5	156	202	36 2	60 2	96 0	58 7	0 93	1 39	217	134
Skeletal muscle	3 5	0 01	0 9	98 1	2.3	0 01	175	21 4	67 6	148	93 8	6 8	0 5	36 7	3 4	0 01	0 01	33 8	35 0
Cardiac muscle	2.0	0 01	0.3	5 0	0 6	0 01	62 6	1 7	29 0	125	482	5 2	1 1	52 5	3 0	0 2	0 1	0	0
Uterus	2.2	0 01	0 01	0 9	0 01	0 01	37 5	2 7	11 1	25 6	33 8	1 1	1 1	4 1	0 9	0 9	0 01	15 0	23 1
Stomach muscles	2 3	0 3	0 1	2 6	0 05	0 01	57 4	5 2	17 6	54 1	49 8	2 8	0 7	4 3	0 05	0 5	0 1	0	0
Gastric mucosa	1 1	1 2	0 05	1 1	0 1	0 9	69 8	6 4	22 2	65 7	113	11 0	3 0	28 9	1 1	0 7	0 3	0	0
Pancreas	0 4	0 2	0 09	0 04	0 04	0 1	37 7	3 5	9 8	50 8	47 7	1 8	0 5	3 0	0 7	0 4	0 2	0	0
Renal cortex	2.1	3 6	0 5	1 8	2 4	0 01	108	9 1	15 6	114	105	6 1	6 7	10 6	2 0	0 7	0 5	0	0
Renal medulla	1 1	0 6	0 1	0 7	0 2	0 05	57 8	3 3	23 5	101	49 2	4 4	2 2	8 2	0 7	0 3	0 3	0	0
Cerebral cortex	3 2	0 2	0 1	5 3	0 09	0 01	69 3	10.5	28 5	54 6	117	0 8	4 1	20 3	0 1	0.3	0 3	0	0
Cerebrum	1 0	0 2	0 04	2 5	0 2	0 01	69 1	7 7	27 9	40 1	61 8	0 9	2 3	9 3	0 01	0 2	0 1	0	0
Cerebellar hemispheres	1 8	0 1	0 07	4 7	0 01	0 01	69 7	12 4	34 9	64 7	78 4	0 2	1 5	21 6	0 07	0 3	0 3	0	0
Lungs	1 4	1 6	0 04	0 5	0 1	0 3	27 3	2 6	8 6	27 4	27 3	1 1	2 5	1 1	0 1	0 6	0 5	0	0
Fatty tissues	0 7	0 01	0 1	1 6	4 3	0 2	19 4	1 6	3 8	52 8	72 7	1 7	1 3	5 2	1 9	1 5	1 2	0	0
Lymph glands	3 7	0 2	0 09	3 4	0 1	0 2	75 3	10 8	30 4	84 0	69 7	4 1	2 7	7 4	0 07	0 9	0 5	0	0
Erythrocytes	2.0	0	0	17.3	0	0	198	18 9	32 8	171	125	1 2	0	6 8	1 4	13 2	7 1	289	64 2
foetal	1 5	0	0	14 9	1 9	0	284	30 3	23.3	357	304	2 7	0	14 3	1 3	28 5	8 2	600	75 4
Thrombocytes	4 5	0	0	8 2	1 2	0	39 0	23 6	120	97 7	37 2	3 3	0 7	1 6	0 8	6 9	0 9	82 7	39 4
Granulocytes	174	0	0	406	159	0	5 29 $\times 10^3$	3 38 $\times 10^3$	368	9 92 $\times 10^3$	2 43 $\times 10^3$	166	23 8	271	82 3	926	342	11 7 $\times 10^3$	4 16 $\times 10^3$

(For references see pages 588–589)

Table 4 Enzyme concentration gradients[4]

	Skeletal muscle/ serum	Liver/ serum
Fructosediphosphate aldolase	21800:1	2700:1
Pyruvate kinase	6200:1	1400:1
Lactate dehydrogenase	1400:1	1400:1
Malate dehydrogenase	2000:1	2600:1
Aspartate aminotransferase	5700:1	9000:1
Alanine aminotransferase	750:1	7600:1

variance in the values) between maximum nocturnal and minimum noon levels have been reported[37] as well as marked constancy throughout the day[38].

Muscular work. Heavy muscular work causes a marked rise in serum enzyme activities. In untrained test subjects, long-continued work resulted in considerable increases in the levels of aspartate aminotransferase, alanine aminotransferase, lactate dehydrogenase, fructosediphosphate aldolase, malate dehydrogenase, pyruvate kinase and creatine kinase[27, 39–41], the last-named enzyme being markedly sensitive even to quite mild physical exertion[39, 42]. Alkaline and acid phosphatases, as well as amylase, show no change[33].

Pregnancy. During uneventful pregnancy the serum activities of many enzymes – for instance aspartate aminotransferase, alanine aminotransferase, fructosediphosphate aldolase, isocitrate dehydrogenase, malate dehydrogenase and α-hydroxybutyrate dehydrogenase–remain within the normal range[43–50]. There have been reports of irregular increases in aspartate aminotransferase[47], creatine kinase[49] and especially lactate dehydrogenase[47, 48, 51] during the last weeks of gestation, but these have not been confirmed by other workers[44–46, 52].

A number of hydrolytically active enzymes (alkaline phosphatase[45, 47, 53], leucine aminopeptidase[50, 54], oxytocinase[55], β-glucuronidase[50, 56]) as well as histaminase[57] show increases up to many times the normal serum value during pregnancy, with a subsequent return to normal in a few days post partum.

Serum enzyme activities

Most of the diagnostically useful enzymes except those concerned in blood coagulation are best determined in the serum since in the plasma their activity may be inhibited by the presence of added citrate, oxalate, heparin, fluoride, etc.[33]. Even slight haemolysis interferes with the determination of the enzymes present at high activities in the erythrocytes, such as lactate dehydrogenase, glucose-6-phosphate dehydrogenase, phosphogluconate dehydrogenase, fructosediphosphate aldolase, arginase, etc., but it can be tolerated in the case of enzymes whose serum and erythrocyte concentrations differ by much less, such as aspartate aminotransferase, alanine aminotransferase, glutamate dehydrogenase, ketose-1-phosphate aldolase, etc.

In general, determinations should be carried out immediately after collection of the serum sample since enzymes may be unstable in the serum. Most of the diagnostically useful enzymes, however, show little change in activity during the first 24 hours if the serum is kept at + 4 °C or even room temperature[33, 34]. Exceptions are glucose-6-phosphatase, glucose-6-phosphate dehydrogenase, phosphogluconate dehydrogenase and creatine kinase[33]. For methods of enzyme determination see the literature[33, 58].

Elimination of enzymes from the serum

The serum levels of enzymes normally remain fairly constant. Injection of enzymes into the blood is followed by a rapid return to normal values[59–62]. The reduction takes place in two phases[61], a faster phase of distribution over the whole intercellular space and a slower one of actual elimination. The half-lives in human serum, so far known only approximately, of various enzymes are[63–66]: aspartate aminotransferase 46–58 hours, alanine aminotransferase 63–88 hours, lactate dehydrogenase ca. 52 hours.

The mechanism of elimination remains obscure. Alkaline phosphatase and leucine aminopeptidase are excreted in the bile, amylase, pepsinogen and other enzymes of low molecular weight in the urine. Nevertheless, the rates of excretion of yet other enzymes like aspartate aminotransferase, alanine aminotransferase and la[c] hydrogenase remain unchanged by bilateral nephrectomy, [hepa]tectomy or by splenectomy[59, 61, 63, 67]. The reticuloend[othelial] system may play an important part in enzyme elimination f[rom] blood[68].

Diagnostic use of enzymes

Maintenance of the normal difference between the enzy[me con]centrations in the cells and serum is a process closely linke[d] energy metabolism of the cell. Impairment of energy produ[ction] as in injury to the cell – results in movement of enzymes ou[t] cell[59, 60, 69], the rate depending on the concentration gradie[nt, mo]lecular weight and location of the particular enzyme. The r[elative] importance of these factors varies with the severity of the in[jury to] the cell. When it is acute and severe – as in cardiac infarctio[n] enzyme pattern of the organ appears in the serum, whereas [in] acute and less severe injury the increase in serum enzyme a[ctivity] is mainly accounted for by the readily extractable cytoplasm[ic en]zymes; in the latter case the characteristic enzyme pattern i[s] effaced as a result of the different rates at which the enzym[es are] eliminated[41, 70–72].

The extent to which the serum enzyme activity increases r[eflects] the severity and scope of the cell injury[64, 66, 73]. The seat [of] disease can be established by identifying the typical enzyme p[attern] of the organ in the serum, or by determining 'organ-specifi[c en]zymes or tissue-specific isozyme distributions[74].

Of the many enzymes present in the serum only a few have p[roved] to be of lasting diagnostic value. In order of practical impor[tance] these are: aspartate aminotransferase, alanine aminotransfera[se, al]kaline phosphatase, acid phosphatase, amylase, creatine ki[nase,] glutamate dehydrogenase, lactate dehydrogenase (and its isozy[mes),] iditol dehydrogenase and fructosediphosphate aldolase. En[zyme] determinations now play an indispensable part in the diagno[sis of] liver, heart, muscle and pancreatic diseases.

1. Liver disease. In *acute hepatitis* there is an increase in most o[f the] serum enzymes so far studied[75]. Aspartate aminotransferase a[ctiv]ity rises 10–150 times, that of alanine aminotransferase 20 times. The increase in alkaline phosphatase activity is comparati[vely] small and reflects the accompanying biliary obstruction[76]. T[here] is a decrease in the plasma cholinesterase activity originating i[n the] liver[77]. The increase in enzyme activity precedes the rise in bilirubin concentration and thus allows diagnosis of hepatit[is in] anicteric patients[78]. The course of the disease can readily be [fol]lowed with the aid of enzyme determinations, an aggravatio[n or] relapse always being manifested by a renewed rise in the serum [en]zyme levels[76]. Failure of the aminotransferase activities to re[turn] to normal in spite of apparent clinical healing is an indication [that] hepatitis persists in a subchronic form[76].

A smaller rise in serum aminotransferase activities (2–8 ti[mes] the normal) occurs in active *chronic hepatitis* and *cirrhosis of liver*[76, 79–81]. In cases of long standing the aspartate aminotr[ans]ferase level is usually higher than the alanine aminotransferase le[vel,] with a fairly marked rise in glutamate dehydrogenase activity. These enzyme changes are quite distinct from those seen in ac[ute] hepatitis and are characteristic of the necrotic type of cell injury.

Any aggravation of the disease, whether marked by jaund[ice] or not, results in an immediate rise in serum enzyme acti[vi]ties[76, 79, 81, 82]. In protracted *hepatic coma* a fall in aminotransfer[ase] activity must be regarded as an unfavourable sign[81, 83–85]; ot[her] enzymes – lactate dehydrogenase, malate dehydrogenase, keto[se-] 1-phosphate aldolase, etc. – show large increases in activity[76].

In the terminal stages of *cirrhosis of the liver with ascites* the ove[rall] enzyme activity shows little pathological change; the aspart[ate] aminotransferase activity is always higher than the alanine amir[no]transferase activity, however, while glutamate dehydrogenase c[an] often be detected. These very small increases in aminotransfera[se] activity enable the terminal stages to be distinguished from the s[o-] called 'early' ascites accompanying acute aggravations of the d[is]ease, in which aminotransferase activity is very markedly increas[ed] owing to the severe injury to the cells[76].

In *adipohepatic liver* there are merely slight changes in serum e[n]zyme activities. Marked increases are seen only in very severe fat degeneration or in the presence of secondary inflammation[76, 8...]. Extremely high increases – up to 10000 U/l for aspartate and alani[ne] aminotransferases and lactate dehydrogenase – occur in *acute po[i]soning*, especially with organic solvents[64, 87]. A rise in serum e[n]zyme activities following acute *alcohol intoxication* is seen only i[n] alcoholics and cannot be produced experimentally in healthy pe[r]sons[88].

Primary *carcinoma of the liver* in the presence of cirrhosis of the liver is not marked by any further change in the serum enzyme pattern[87, 89]. In *carcinomatous metastases of the liver* there is a moderate overall increase in enzyme activity, with higher aspartate aminotransferase than alanine aminotransferase activity[75, 76], and a distinct increase in glutamate dehydrogenase activity[76], while lactate dehydrogenase levels often exceed 500 U/l[75, 76]. High alkaline phosphatase values are often also found in the absence of jaundice[90, 91].

In *obstructive jaundice*, diagnostic criteria are the markedly lower increase in aminotransferase activities compared to acute hepatitis[87, 91, 92] and the rise in alkaline phosphatase[93] and leucine aminopeptidase[94, 95] activities. Quite often, however, particularly following biliary colic, there are rises in aminotransferase activity like those seen in the milder forms of acute hepatitis[41, 91, 96]. Another feature often seen is absence of any corresponding increase in alkaline phosphatase activity. The diagnosis can be strengthened by measuring the ratio (aspartate aminotransferase + alanine aminotransferase)/glutamate dehydrogenase[97]; in inflammatory icteric liver disease this is over 30, in obstructive jaundice less than 15

2. Heart disease. A rise in serum enzyme activity is a constant (95–100% of patients) and reliable sign of *cardiac infarction*[98, 99]. When injury to the cells is acute and short-lived the timely measurement of enzyme activities is particularly important[78].

The relatively small mass of muscle damaged in cardiac infarction means that the increase in enzyme activity is markedly less than in acute liver disease. In general, the creatine kinase and aspartate aminotransferase activities reach values 10 times the normal, the lactate dehydrogenase and fructosediphosphate aldolase activities values 3–6 times the normal[74, 75]. The clear correlation between the size of the infarct and the level of serum enzyme activity ob- [illegible]

[illegible] rise in enzyme activity[75]. The enzyme pattern in the serum resembles that in the myocardium, namely higher aspartate amino- [illegible]

In *angina pectoris*, serum enzyme activities remain unchanged[101]. If the symptoms are severe and an increase in enzyme activity is observed, there is a high probability that infarction has occurred even though the typical ECG changes are not recorded[102].

Changes in serum enzyme activity are also associated with various types of *tachycardia* of frequency exceeding 160/min[88, 103] and are due to congestion of the liver.

Pulmonary embolism can be distinguished from cardiac infarction [illegible]

Table 5 Serum enzyme activities following cardiac infarction[?]

	Starts to rise at (hours)	Maximum activity at (hours)	Return norm after (d
Creatine kinase	2–4	24–36	3–6
Aspartate aminotransferase . .	4–6	24–48	4–7
Lactate dehydrogenase	8–10	48–72	8–9
Lactate dehydrogenase isozymes 1 and 2	8–10	24–92	10–1[illegible]
Fructosediphosphate aldolase	4–6	24–48	2–9

3. Muscular disease. After severe *muscular injury* there is a slight [illegible] particularly in those enzymes with a high activity in muscle, nam[illegible] creatine kinase, aspartate aminotransferase and fructosediph[illegible] phate aldolase. Very marked increases in activity are observed [illegible] *muscular dystrophy*, especially of the DUCHENNE type[109–112]; in ot[illegible] types the rise is distinctly smaller and more irregular[109–112]. T[illegible] extent of the increase in enzyme activity depends on the severity [illegible]

An increase in serum enzyme activities is also seen in *chronic po[illegible] myositis*[110, 114, 115], in *dystrophia myotonica*[110, 114, 116] and in *derma[illegible] myositis*; in the latter disease, lactate dehydrogenase and gluco[illegible] phosphate isomerase are especially prominent, and the aminotra[illegible] ferase activity may reach 400–600 U/l[117].

[illegible] istic and are indicative merely of primary or secondary involv[illegible] ment of the liver[98, 118].

In *acute pancreatitis* the serum amylase and lipase activities start [illegible] rise within 3–6 hours and attain a maximum after 20–30 hours. I[illegible] creased activities are still observed after 48–72 hours, after whi[illegible]

hydrogenase, have not been fulfilled. The frequency with which an increased lactate dehydrogenase activity occurs in patients with tumours varies between 40% and 90%[129]. The values for this enzyme, among 26 whose activities in the serum of patients with tumours of very different kinds were studied, proved to be the most regular in their behaviour[130]. They constitute no reliable index, however, since an increase in the lactate dehydrogenase activity is not a constant observation even when tumours are widely disseminated; it is also a feature of a great many other diseases.

The characteristic enzyme pattern seen in carcinomatous metastases of the liver has already been mentioned.

Apart from the diseases mentioned in this chapter, there are many others in which serum enzyme determinations can play a valuable role in the diagnosis and in following the course of the disease. This is particularly so when measurements are made not on a *single* enzyme but on a selected group of two, three or more enzymes whose relationship to the other symptoms of the disease has been established[76].

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Blood – Enzymes

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name Recommended trivial name In brackets: abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks (see also text on pages 584-
1.1.1.1							
Alcohol: NAD oxidoreductase **Alcohol dehydrogenase** (ADH)	Optical[1], modified, 25 °C ...	7	1.8			2	Slight haemolysis does not [...]fere. Clinical importance sm[...] to now. Markedly increased [...]rum in acute hepatitis and [...] acute liver disease of a seve[...]ture[2,3].
1.1.1.8							
L-Glycerol-3-phosphate: NAD oxidoreductase **Glycerophosphate dehydrogenase** (GDH)	Optical[4], modified, 25 °C ...	19	2.7	(1.6–6.6)		2, 5	Slight haemolysis does not [...]fere. Increased in serum in [...] hepatitis and severe liver dis[...]
1.1.1.14							
L-Iditol: NAD oxidoreductase **L-Iditol dehydrogenase** (Sorbitol dehydrogenase [SDH])	Optical[6], modified, 24 °C ...	16	0.9			7	Owing to the low activity [...] enzyme in the erythrocytes [...] haemolysis does not interfer[...] tivity high in liver only. A rise [...] serum activity is fairly speci[...] liver damage[5,7,9].
	Optical[7], modified, 25 °C ...	12	1.1			5	
	Optical[7], modified, 25 °C ...	91	0.06	(0–0.4)	0.1	8	
	Optical[7], modified, 37 °C ...	32	0.08	(0–0.6)		9	
	Optical[7], modified, 25 °C						
	Adults			0–3.0		10	
	Cord blood			0–4.5		10	
	Children.................			0–6.0		10	
1.1.1.27							
L-Lactate: NAD oxidoreductase **Lactate dehydrogenase** (LDH)	Optical[11], modified, 24–27 °C	161	225	(120–419)		12	Owing to the high activity o[...] enzyme in the erythrocytes [...] slight haemolysis results in [...] high serum values. Present [...] organs at high activity, so th[...] increase in the serum activit[...] lows severe organic injury o[...] kind. 5 isozymes have been i[...]fied in organs and serum. Det[...]nation of total lactate dehyd[...]nase activity is clinically usef[...] diagnosis of cardiac infarctio[...] differential diagnosis of an[...] (highest values in pernicious [...]mia) and to some extent in [...] disease; for further discussio[...] the literature[20]. For normal v[...] of the isozyme distribution [...] JORDAN and WHITE[20a].
	Optical[13], modified, 25 °C...	130		(125–379)		14	
	Optical[11], modified, 25 °C...	180	88	(36–130)		5	
	Optical[11], modified, room temperature.............	107	71		6.2	15	
	Optical[11], modified, 25 °C...			(30–120)		16	
	Colorimetric (2,4-diphenylhydrazine), 37 °C			(70–240)		16	
	Optical[11], modified, 25 °C...	209	100		22	8	
	Optical[11], modified, 25 °C...	175	144		28.8	17	
	Optical[11], modified, 25 °C						
	Adults	100	140		45	10	
	Cord blood	29	306		118	10	
	1 month	6	306		89	10	
	2–3 months	13	221		44	10	
	4–6 months	12	217		41	10	
	6–12 months	14	197		44	10	
	2 years	12	230		57	10	
	2–16 years	24	145		45	10	
	Optical[11], modified, 25 °C						
	Cord blood	202		(87–580)		18	
	Optical[11], modified, 25 °C						
	Premature infants	25	126			19	
	Newborn	19	114		61	19	
	Infants	36	49		27	19	
	Children.................	38	42		12	19	

1 NEGELEIN and WULFF, *Biochem. Z.*, 293, 351 (1937).
2 SCHMIDT et al., *Klin. Wschr.*, 36, 280 (1958).
3 WOLFSON et al., *Ann. N.Y. Acad. Sci.*, 75, 260 (1958/59).
4 BÜCHER, T., in COLOWICK and KAPLAN (Eds.), *Methods in Enzymology*, vol. 1, Academic Press, New York, 1955, page 415.
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6 HOLZER et al., *Biochem. Z.*, 326, 451 (1955).
7 GERLACH, U., *Klin. Wschr.*, 37, 93 (1959).
8 FEISSLI et al., *Klin. Wschr.*, 44, 390 (1966).
9 WÜST and SCHÖN, *Klin. Wschr.*, 39, 280 (1961).
10 GAUTIER et al., *Helv. paediat. Acta*, 17, 415 (1962).
11 KUBOWITZ and OTT, *Biochem. Z.*, 314, 94 (1943).
12 WRÓBLEWSKI and LADUE, *Proc. Soc. exp. Biol. (N.Y.)*, 90, 210 (1955).
13 STROMINGER and LOWRY, *J. biol. Chem.*, 213, 635 (1955).
14 HSIEH and BLUMENTHAL, *Proc. Soc. exp. Biol. (N.Y.)*, 91, 626 (1956).
15 ENGLHARDT-GOLKEL et al., *Klin. Wschr.*, 36, 462 (1958).
16 KING, J., *Practical Clinical Enzymology*, Van Nostrand, London, 1965.
17 SCHNEIDER et al., *Med. Klin.*, 60, 6 (1965).
18 HAUG and KLUGE, *Klin. Wschr.*, 43, 680 (1965).
19 STAVE, U., *Z. Kinderheilk.*, 81, 472 (1958).
20 WILKINSON, J.H., *An Introduction to Diagnostic Enzymology*, Arnold, Lon[...] 1962; HESS, B., *Enzyme im Blutplasma*, Thieme, Stuttgart, 1962; A[...]LUNG, D., *Fermentdiagnostik interner Erkrankungen*, Thieme, Stuttgart, 1[...]
20a JORDAN and WHITE, *Clin. chim. Acta*, 15, 457 (1967).

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name **Recommended trivial name** In brackets abbreviation and non recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks (see also text on pages 584–588)
[α-Hydroxybutyrate dehydrogenase] (HBDH)	Optical[21, 22], 25 °C	42	90		38	23	Not in itself an enzyme but derives from the simple method of determining the electrophoretically fast-migrating isozymes of lactate dehydrogenase[21] These are present at high activity in heart muscle and brain and oxidize hydroxybutyrate to a much greater extent than the isozymes mainly present in skeletal muscle and liver For practical purposes the ratio LDH/HBDH equals the ratio total LDH isozymes/heart-muscle specific LDH isozymes, normal value in 42 adults[23] 1 40, in 155 adults[17] 1 34
	Optical[21, 22], 25 °C	175	108		23 5	17	
	Optical[21, 22], 25 °C	100	77		36	24	
	Optical[21, 22], 25 °C						
	Adults	152	76		30	25	
	Cord blood	15	211		164	25	
1.1.1 37 L-Malate NAD oxidoreductase **Malate dehydrogenase** (MDH)	Optical[26], modified, 25 °C	28	37.9	(17.0–57.3)		5	Owing to the high activity of this enzyme in the erythrocytes even slight haemolysis results in 'false' high serum values In the neonatal period the upper limit of the normal may be up to 100 U/l[28] Diagnostic importance so far slight Present in all organs at high activity, so that an increase in the serum activity follows severe organic injury of any kind, for instance cardiac infarction, liver damage, blood disease For reviews see the literature[20]
	Optical[27], modified, 25 °C	107	23 5		3 4	15	
	Optical[26], modified, 25 °C	88	71		17	8	
	Optical[26], modified, 25 °C						
	Adults			(12 5–50)		16	
	Cord blood	202		(93 4–265)		18	
1 1.1.38 (40) L-Malate NAD(P) oxidoreductase (decarboxylating) **Malate dehydrogenase (decarboxylating)** ('Malic' enzyme)	Optical[29], 25 °C	30		(0–0 5)		30	
1.1.1 42 *threo*-Ds-Isocitrate NADP oxidoreductase (decarboxylating) **Isocitrate dehydrogenase** (ICDH)	Optical[31], 25 °C	44	2 0	(0 86–4 8)		31	Slight haemolysis does not interfere In cord blood the activity is much higher than in the blood of adults but falls within 10 days[16], other studies[33] showed little difference The serum activity increases in liver damage[2] In cardiac infarction it is either unchanged[34] or shows only a slight and transient rise[36]
	Optical[32], room temperature	38	1 3	(0 96–1 9)		32	
	Optical[27], modified, 25 °C						
	Adults	13	3 5	(1 0–7 3)		8	
	Cord blood	30	3 7		2 6	33	
1.1 1 44 6-Phospho-D-gluconate NADP oxidoreductase (decarboxylating) **Phosphogluconate dehydrogenase (decarboxylating)** (PGDH)	Optical[31], 25 °C	26	2 5	(0 7–4 0)		31	Owing to the high activity of this enzyme in the erythrocytes even slight haemolysis results in 'false' high serum values The serum activity is normal during pregnancy, in cord blood rather higher than in the blood of adults Diagnostic importance so far small The activity increases in acute hepatitis[2, 3] and blood disease[37] Its determination in vaginal fluid has been suggested as a test for gynaecological cancer[38]
	Optical[36], modified, 25 °C	17	1 0			8	

[21] ROSALKI and WILKINSON, *Nature*, 188 1110 (1960)
[22] ELLIOTT and WILKINSON, *Lancet*, 1, 698 (1961)
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[33] PEHRSON, S L., *Acta obstet gynec scand*, 43, 69 (1964)
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Blood – Enzymes

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name **Recommended trivial name** In brackets: abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks (see also text on pages 5
1.1.1.1 Alcohol:NAD oxidoreductase **Alcohol dehydrogenase** (ADH)	Optical[1], modified, 25 °C ...	7	1.8			2	Slight haemolysis does : fere. Clinical importance to now. Markedly increa rum in acute hepatitis : acute liver disease of a : ture[2,3].
1.1.1.8 L-Glycerol-3-phosphate: NAD oxidoreductase **Glycerophosphate dehydrogenase** (GDH)	Optical[4], modified, 25 °C ...	19	2.7	(1.6–6.6)		2, 5	Slight haemolysis does : fere. Increased in serum hepatitis and severe liver
1.1.1.14 L-Iditol:NAD oxido-reductase **L-Iditol dehydrogenase** (Sorbitol dehydrogenase [SDH])	Optical[6], modified, 24 °C ...	16	0.9			7	Owing to the low activi enzyme in the erythrocy haemolysis does not inte tivity high in liver only. A serum activity is fairly sp liver damage[5,7,9].
	Optical[7], modified, 25 °C ...	12	1.1			5	
	Optical[7], modified, 25 °C ...	91	0.06	(0–0.4)	0.1	8	
	Optical[7], modified, 37 °C ...	32	0.08	(0–0.6)		9	
	Optical[7], modified, 25 °C						
	Adults			0–3.0		10	
	Cord blood			0–4.5		10	
	Children			0–6.0		10	
1.1.1.27 L-Lactate:NAD oxido-reductase **Lactate dehydrogenase** (LDH)	Optical[11], modified, 24–27 °C	161	225	(120–419)		12	Owing to the high activi enzyme in the erythrocy slight haemolysis results high serum values. Prese organs at high activity, s increase in the serum act lows severe organic injur kind. 5 isozymes have bee fied in organs and serum. nation of total lactate de nase activity is clinically diagnosis of cardiac infar differential diagnosis of (highest values in pernicic mia) and to some extent disease; for further discu the literature[20]. For norm of the isozyme distribu JORDAN and WHITE[20a].
	Optical[13], modified, 25 °C...	130		(125–379)		14	
	Optical[11], modified, 25 °C...	180	88	(36–130)		5	
	Optical[11], modified, room temperature	107	71		6.2	15	
	Optical[11], modified, 25 °C...			(30–120)		16	
	Colorimetric (2,4-diphenyl-hydrazine), 37 °C			(70–240)		16	
	Optical[11], modified, 25 °C...	209	100		22	8	
	Optical[11], modified, 25 °C...	175	144		28.8	17	
	Optical[11], modified, 25 °C						
	Adults	100	140		45	10	
	Cord blood	29	306		118	10	
	1 month	6	306		89	10	
	2–3 months	13	221		44	10	
	4–6 months	12	217		41	10	
	6–12 months	14	197		44	10	
	2 years	12	230		57	10	
	2–16 years	24	145		45	10	
	Optical[11], modified, 25 °C						
	Cord blood	202		(87–580)		18	
	Optical[11], modified, 25 °C						
	Premature infants	25	126			19	
	Newborn	19	114		61	19	
	Infants	36	49		27	19	
	Children	38	42		12	19	

1 NEGELEIN and WULFF, *Biochem. Z.*, 293, 351 (1937).
2 SCHMIDT et al., *Klin. Wschr.*, 36, 280 (1958).
3 WOLFSON et al., *Ann. N.Y. Acad. Sci.*, 75, 260 (1958/59).
4 BÜCHER, T., in COLOWICK and KAPLAN (Eds.), *Methods in Enzymology*, vol. 1, Academic Press, New York, 1955, page 415.
5 SCHMIDT et al., in BERGMEYER, H.-U. (Ed.), *Methoden der enzymatischen Analyse*, Verlag Chemie, Weinheim/Bergstr., 1962, page 703.
6 HOLZER et al., *Biochem. Z.*, 326, 451 (1955).
7 GERLACH, U., *Klin. Wschr.*, 37, 93 (1959).
8 FEISSLI et al., *Klin. Wschr.*, 44, 390 (1966).
9 WÜST and SCHÖN, *Klin. Wschr.*, 39, 280 (1961).
10 GAUTIER et al., *Helv. paediat. Acta*, 17, 415 (1962).
11 KUBOWITZ and OTT, *Biochem. Z.*, 314, 94 (1943).
12 WRÓBLEWSKI and LADUE, *Proc. Soc. exp. Biol. (N.Y.)*, 90, 210 (195
13 STROMINGER and LOWRY, *J. biol. Chem.*, 213, 635 (1955).
14 HSIEH and BLUMENTHAL, *Proc. Soc. exp. Biol. (N.Y.)*, 91, 626 (1956
15 ENGLHARDT-GÖLKEL et al., *Klin. Wschr.*, 36, 462 (1958).
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17 SCHNEIDER et al., *Med. Klin.*, 60, 6 (1965).
18 HAUG and KLUGE, *Klin. Wschr.*, 43, 680 (1965).
19 STAVE, U., *Z. Kinderheilk.*, 81, 472 (1958).
20 WILKINSON, J. H., *An Introduction to Diagnostic Enzymology*, Arnold, I 1962; HESS, B., *Enzyme im Blutplasma*, Thieme, Stuttgart, 1962 LUNG, D., *Fermentdiagnostik interner Erkrankungen*, Thieme, Stuttgar
20a JORDAN and WHITE, *Clin. chim. Acta*, 15, 457 (1967).

Blood – Enzymes

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name Recommended trivial name In brackets abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks (see also text on pages 584–588)
[α-Hydroxybutyrate dehydrogenase] (HBDH)	Optical[21,22], 25 °C	42	90		38	23	Not in itself an enzyme but derives from the simple method of determining the electrophoretically fast-migrating isozymes of lactate dehydrogenase[27]. These are present at high activity in heart muscle and brain and oxidize hydroxybutyrate to a much greater extent than the isozymes mainly present in skeletal muscle and liver For practical purposes the ratio LDH/HBDH equals the ratio total LDH isozymes/heart-muscle specific LDH isozymes, normal value in 42 adults[23] 1.40, in 155 adults[17] 1 34
	Optical[21,22], 25 °C	175	108		23.5	17	
	Optical[21,22], 25 °C	100	77		36	24	
	Optical[21,22], 25 °C						
	Adults	152	76		30	25	
	Cord blood	15	211		164	25	
1.1.1.37 L-Malate·NAD oxidoreductase **Malate dehydrogenase** (MDH)	Optical[26], modified, 25 °C	28	37.9	(17 0–57.3)		6	Owing to the high activity of this enzyme in the erythrocytes even slight haemolysis results in 'false' high serum values In the neonatal *period the upper limit of the normal* may be up to 100 U/l[28]. Diagnostic importance so far slight Present in all organs at high activity, so that an increase in the serum activity follows severe organic injury of any kind, for instance cardiac infarction, liver damage, blood disease For reviews see the literature[20].
	Optical[27], modified, 25 °C	107	23 5		3.4	16	
	Optical[28], modified, 25 °C	88	71		17	8	
	Optical[28], modified, 25 °C						
	Adults			(12 5–50)		16	
	Cord blood	202		(93.4–265)		18	
1.1 1 38 (40) L-Malate NAD(P) oxidoreductase (decarboxylating) **Malate dehydrogenase (decarboxylating)** ('Malic' enzyme)	Optical[29], 25 °C	30		(0–0 5)		30	
1 1 1 42 *threo*-D$_s$-Isocitrate NADP oxidoreductase (decarboxylating) **Isocitrate dehydrogenase** (ICDH)	Optical[31], 25 °C	44	2.0	(0 86–4 8)		31	Slight haemolysis does not interfere In cord blood the activity is much higher than in the blood of adults but falls within 10 days[18], other studies[33] showed little difference The serum activity increases in liver damage[2]. In cardiac infarction it is either unchanged[34] or shows only a slight and transient rise[35].
	Optical[32], room temperature	38	1.3	(0 96–1.9)		32	
	Optical[27], modified, 25 °C						
	Adults	13	3 5	(1 0–7 3)		8	
	Cord blood	30	3.7		2 6	33	
1 1 1 44 6-Phospho-D-gluconate NADP oxidoreductase (decarboxylating) **Phosphogluconate dehydrogenase (decarboxylating)** (PGDH)	Optical[31], 25 °C	26	2 5	(0 7–4 0)		31	Owing to the high activity of this *enzyme in the erythrocytes* even slight haemolysis results in 'false' high serum values The serum activity is normal during pregnancy, in cord blood rather higher than in the blood of adults Diagnostic importance so far small The activity increases in acute hepatitis[2,3] and blood disease[37]. Its determination in vaginal fluid has been suggested
	Optical[36], modified, 25 °C	17	1 0			8	

Blood – Enzymes

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name **Recommended trivial name** In brackets: abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks (see also text on pages 5l
1.1.1.49 D-Glucose-6-phosphate: NADP oxidoreductase **Glucose-6-phosphate dehydrogenase** (G-6-PDH) ('Zwischenferment' [ZF])	Optical[39], room temperature	67	1.4	(0.5–2.4)		32	Even slight haemolysis r 'false' high serum values activity increased in acut tis[2], cardiac infarction[40] a severe tissue damage. (useful when deficiency of zyme in the erythrocytes suspected (primaquine sen as in favism and kernicter
	Optical[39], modified, 25 °C ..	18	1.0			5	
	Optical[39], modified, 25 °C ..	38	0.24		0.29	8	
1.2.1.12 D-Glyceraldehyde-3-phosphate:NAD oxidoreductase (phosphorylating) **Glyceraldehyde-phosphate dehydrogenase** **Triosephosphate dehydrogenase** (GAPDH)	Optical[42], modified, 25 °C ..	20	7.1	(1.0–11.2)		5	*Even slight haemolysis in* considerably. Clinical imp so far small. *Serum activit* creased in acute hepatitis[2] tious mononucleosis[43] and kinds of tumour[30].
1.2.3.2 Xanthine:oxygen oxidoreductase **Xanthine oxidase** (Hypoxanthine oxidase)	Substrate: 8-^{14}C-xanthine[44], 25 °C	20		(0–0.0005)		44	Clinical importance so far Serum activity increased i damage[44].
1.3.99.1 Succinate: (acceptor) oxidoreductase **Succinate dehydrogenase**	Optical[45]			Not detectable		15	Structurally bound enzyme. not detected in serum even in organic injury.
1.4.1.3 L-Glutamate:NAD(P) oxidoreductase (deaminating) **Glutamate dehydrogenase** (GLDH)	Optical[6], modified, 25 °C ...		1.0			46	Slight haemolysis does not fere. Largely specific to the Serum activity increased in in matory liver disease and obs tive jaundice[46, 47], which ca differentiated by means of the (aspartate aminotransferase+ nine aminotransferase)/gluta dehydrogenase[47–49].
	Optical[6], modified, 25 °C ...	127	1.0			47	
	Optical (Boehringer), 25 °C .	243	0.39	< 0.8	0.28	8	
1.6.4.2 Reduced-NAD(P):oxidized-glutathione oxidoreductase **Glutathione reductase** (GR)	Optical[50]			(5–35)		16	Serum activity markedly incre *in acute hepatitis and leukaem* less so in cirrhosis. Also incre in 35–80% of patients with seminated carcinomas[32, 52]. *In* maquine-sensitive patients, wl erythrocytes are poor in gluco phosphate dehydrogenase, the tathione reductase activity of *cells is doubled*[53].
	Optical[51], 25 °C						
	NAD	10	7.0	(3.3–10.2)		51	
	NADP	10	12.6	(4.3–17.4)		51	
	Optical[50], NADP..........	98	19.2		7.2	52	

39 Kornberg and Horecker, in Colowick and Kaplan (Eds.), *Methods in Enzymology*, vol. 1, Academic Press, New York, 1955, page 323.
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52 Manso and Wróblewski, *J. clin. Invest.*, 37, 214 (1958).
53 Schrier et al., *J. Lab. clin. Med.*, 52, 109 (1958).

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name commended trivial name brackets abbreviation and recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks (see also text on pages 584–588)
ruloplasmin)	Colorimetric (*p*-phenylenediamine)[54], 37 °C						Caeruloplasmin has the properties of *p*-diphenol oxidase In pregnancy the caeruloplasmin activity is 2–3 times higher than normal[55]. A deficiency of the enzyme is characteristic of hepatolenticular degeneration[56], but is also found in the nephrotic syndrome, kwashiorkor[57] and sprue[58]. The serum activity is increased in cardiac infarction, infectious diseases, leukaemia, etc.[16].
	Adults			19–45		10	
	Cord blood			3 3–16 7		10	
	1–3 months			12 1–39		10	
	Children			19 2–60		10	
3 3							
ɔamoylphosphate L-ornie carbamoyltransferase	Microdiffusion[59], modified[60], 37 °C			(0–0 25)		16	Increased in 25% of normal pregnancies In cord blood the activity is the same as in normal adults. The observation of an increase in serum activity from the age of 24 years on[63] has not been confirmed[64] The high activity of the enzyme in the liver renders the serum activity a specific index of severe liver damage
ithine carbamoyl-sferase	Colorimetric[61], 37 °C			(8–20)		61	
T)	Isotopic[62], 37 °C			(0–0 07)		62	
1.1							
oheptulose-7-phosphate·lyceraldehyde-3-phosphate colaldehydetransferase	Colorimetric (assay of sedoheptulose 7-phosphate)[65], 37 °C	15	0 82	(0.38–1.42)		65	Serum activity increased in uraemia and often in acute hepatitis, normal in cardiac infarction, cirrhosis of the liver and obstructive jaundice[65]
nsketolase colaldehydetransferase		21	0 29	(0 17–0 60)		66	
1 1							
spartate 2-oxoglutarate inotransferase	Optical[67], 20–22 °C	500	10 6	(2 4–19 2)	3 2	68	Slight haemolysis interferes hardly at all The clinical importance of this enzyme lies in the marked improvement it has brought about in the diagnosis of cardiac infarction and liver disease For reviews see the literature[20 49 72]
partate aminotransferase	Optical[67], 38 °C	160	16 6		0 4	69	
utamate-oxalacetate transinase [GOT])	Optical[67], modified, 25 °C	105	8 0	(3 6–17 0)		5	
	Optical (Boehringer), 25 °C, blood donors	950	12 0	(6 2–22 0)		70	
	Optical[67], 25 °C, blood donors	100	13 6		3.2	10	
	Optical[67], 25 °C			(4–15)		16	
	Colorimetric[71], modified, 25 °C			(5–18)		16	
	Optical (Boehringer), 25 °C	577	7 67		1 8	8	
	Optical[67], 25 °C						
	Cord blood	44	21.3		9.5	10	
	Up to 1 month	12	20 4		9 7	10	
	2–3 months	13	22 6		6 3	10	
	4–6 months	12	24 3		5 5	10	
	7–12 months	16	19 3		5 4	10	
	2 years	6	15 7		4 8	10	
	2–16 years	58	14 1		3 9	10	
	16 years	49	14 4		4 0	10	
	Cord blood	15	12 6		9 0	25	
	Cord blood	202		(0–29)		18	
	Optical[67], 25 °C						
	Premature infants	25	9 2		9 4	19	
	Newborn	20	8 8		4 5	19	
	Infants	41	4 8		2 6	19	
	Children	43	3 7		[illegible]	[illegible]	

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name Recommended trivial name In brackets: abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks (see also text on pages
2.6.1.2 L-Alanine:2-oxoglutarate aminotransferase **Alanine aminotransferase** (Glutamate-pyruvate-transaminase [GPT])	Optical[73], modified, room temperature	54	3.7		2.1	74	Slight haemolysis does fere. High activity in li cally none in erythroc activity increased mark disease, in the diagnosis is the most important e reviews see the literatur
	Optical[73], 20–22 °C	260	7.7	(2.4–16.8)		73	
	Optical[73], modified, 25 °C	122	6.9	(2.9–16.1)		5	
	Optical (Boehringer), 25 °C, blood donors	2400		(6.4–16.0)		70	
	Optical[73], 25 °C, blood donors	2400		(6.4–16.0)		75	
	Optical (Boehringer), 25 °C	722	5.54		1.7	8	
	Cord blood	44	5.0		2.3	10	
	1 month	11	4.0		3.0	10	
	2–3 months	11	7.5		1.6	10	
	4–12 months	14	6.2		2.7	10	
	From 1 year	31	6.8		3.3	10	
	Cord blood	202		0.5–9.6		18	
2.7.1.1 ATP:D-hexose 6-phosphotransferase **Hexokinase** (HK)	Optical, with glucose 6-phosphate dehydrogenase, 25 °C	30		Not detectable		15	Haemolysis interferes. usefulness so far. Serum creased in acute hepatiti
	Optical, 25 °C	7	0.1			5	
2.7.1.3 ATP:D-fructose 1-phosphotransferase **Ketohexokinase** (Fructokinase [FK])	Optical[76], modified, 25 °C	30		Not detectable		30	No clinical usefulness so activity increased in ac tis[30].
2.7.1.40 ATP:pyruvate phosphotransferase **Pyruvate kinase** (PK)	Optical[42], modified, 25 °C	19	16.4	(3.8–34.8)		5	No clinical significance. hepatitis the serum acti a non-significant reducti bed-rest?)[2], in patients mours an increase[30]. spherocytic haemolytic ar erythrocytes have been be deficient in this enzym
	Optical[42]	20	29.9	(15.7–49.6)		77	
	Optical[42], modified, 25 °C	30	15.8		6.0	30	
2.7.2.3 ATP:3-phospho-D-glycerate 1-phosphotransferase **Phosphoglycerate kinase** (PGK)	Optical[4], modified, room temperature	107	11.2		3.1	15	Serum activity increased mia[15]. In cardiac infar acute hepatitis normal[15] higher values[49] have bee
2.7.3.2 ATP:creatine phosphotransferase **Creatine kinase** (Creatine phosphokinase [CPK])	Colorimetric[79], 37 °C			(3.3–23.7)		79	Slight haemolysis does fere. Higher serum acti found following physical [85]. In men the normal slightly higher than in wo Creatine kinase is a sensiti in the diagnosis of ca muscular diseases. For re the literature[20].
	Colorimetric[80], 37 °C			(5.5–75)		81	
	Optical[82], 37 °C	254	0.40		1.3	83	
	Optical (Boehringer), 25 °C	257	0.30	< 1.0	0.30	8	
	Optical (Boehringer), 25 °C	30		(0–0.48)		84	
	Optical[82], 37 °C						
	Adults		1.0		0.8	25	
	Cord blood		2.1		1.8	25	
	Pregnancy, 3rd trimester		2.9		5.6	25	

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Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name **Recommended trivial name** In brackets abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks (*see also text on pages 584–588*)
2.7.4.3 ATP:AMP phosphotransferase **Adenylate kinase** (Myokinase [MK])	Optical[86], 25 °C	25	8.7		3.1	87	In striped muscle the absolute activity of adenylate kinase is higher than that of creatine kinase[86]. Occurs at relatively high activities in leucocytes and thrombocytes. The usefulness of serum determinations in the diagnosis of cardiac and muscular diseases is limited by the necessity of using serum completely free of haemolysis[87]
2.7.5.1 α-D-Glucose-1,6-diphosphate: α-D-glucose-1-phosphate phosphotransferase **Phosphoglucomutase** **Glucose phosphomutase** (PGluM)	Fructose 6-phosphate assay[89], 37 °C	10	8.3	(1.7–23.4)		89	Slight haemolysis does not interfere. In cord blood, values only half as high as in adults have been found. Little clinical importance. Increased in liver damage[91]
	Fructose 6-phosphate assay[89], 37 °C	30	9.8		5.2	90	
	Glucose 1-phosphate assay[90], 37 °C		9.2	(4–17)	3.4	90	
3.1.1.3 Glycerol-ester hydrolase **Lipase**	Titrimetric (substrate olive oil), 37 °C	68	78		29	92	Haemolysis interferes because of inhibition of the reaction by the haemoglobin. No sex specific differences have been observed[93]. The marked increase in the serum activity in acute pancreatitis has so far found little diagnostic application[94]. In chronic pancreatitis the changes are not reliable, better results are obtained with provocation tests[95]. Slight increases in serum lipase activity are seen in inflammatory liver diseases[96]
	Titrimetric (substrate olive oil), 37 °C			(18–285)		16	
	Titrimetric (substrate phenyl laurate), 37 °C			(9–20)		18	
3.1.1.8 Acylcholine acyl hydrolase **Cholinesterase** (CHE)	Colorimetric (acetylcholine bromide), 37 °C			(2000–5200)		97	Slight haemolysis does not interfere. In cord blood the serum activity is rather low but becomes normal after the 10th day, after 2 months the value is about 25% higher than in adults. Serum activity is lower *in hepatitis and cirrhosis, in accordance* with the reduced serum albumin level[102]. Determination of serum cholinesterase activity has its most important application in detecting poisoning by organic phosphorus compounds (insecticides[103]) *and assessing tolerance to muscle* relaxants[104]. Hereditary deficiency of the enzyme, in which atypical enzyme variants may occur, can be detected by determining the dibucaine number
	Optical (benzoylcholine), 25 °C			(620–1370)		98	
	Colorimetric (phenyl benzoate), 37 °C			(3200–7000)		99	
	Optical (benzoylcholine), 25 °C	60	1026		233	24	
	Colorimetric (acetylcholine), 37 °C	250	1530		333	100	
	Colorimetric (benzoylcholine), 37 °C	250	1560		333	100	
	Colorimetric (α-naphthyl propionate), 37 °C	250	3050		466	100	
	Colorimetric (β-naphthyl propionate), 37 °C	250	1750		383	100	
	Colorimetric (phenyl acetate), 37 °C	250	16600		3830	100	
	Colorimetric (monosuccinylcholine), 37 °C	250		< 20		100	
	Colorimetric (disuccinylcholine), 37 °C	250		< 20		100	
	Titrimetric (acetylcholine chloride), 37 °C						
	Men (blood donors)	25	4440		620	101	
	Women (blood donors)	25	3640		680	101	

	KING[16]	RICHTERICH[24]
Normal	80±3	62–90
Heterozygotes	62±8	30–60
Atypical homozygotes	22±6	30

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name Recommended trivial name In brackets: abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks (see also text on pages 584–5
3.1.3.1 Orthophosphoric monoester phosphohydrolase **Alkaline phosphatase**	Substrate phenyl phosphate, 37 °C			(25–92)		105	Serum activity increased in c hood[16,110] and towards ter pregnancy (see page 586). The i important application of serun kaline phosphatase determinati in the diagnosis of liver and b diseases, in the former as indic of the degree of intra- or extr patic biliary obstruction, in the ter as confirmation (when increa of rickets and to a lesser exten osteomalacia. High activities ar so seen in bone tumours and t metastases marked by an increas osteoblasts. *For reviews see* literature[113].
	Substrate *p*-nitrophenyl phosphate, 37 °C			(13.4–38)		106	
	Substrate phenolphthalein phosphate, 37 °C			(0.6–4.2)		107	
	Substrate β-glycerophosphate, 37 °C			(15.1–46.4)		108	
	Substrate β-glycerophosphate, 37 °C			(8.2–21.8)		109	
	Substrate *p*-nitrophenyl phosphate, 37 °C						
	Adults	100	29		8	110	
	Cord blood	15	60		19	110	
	1 month	3	59			110	
	2–3 months	17	98		29	110	
	4–6 months	14	98		32	110	
	7–12 months	15	92		29	110	
	2–15 years	142	88		26	110	
	Substrate phenyl phosphate, 37 °C						
	Newborn			(35–105)		16	
	1 month			(70–250)		16	
	1–3 years			(70–210)		16	
	3–10 years			(70–180)		16	
	10–16 years			(100–275)		16	
	Substrate *p*-nitrophenyl phosphate, optimum conditions[111], 25 °C	73	102	61–171		112	
3.1.3.2 Orthophosphoric monoester phosphohydrolase **Acid phosphatase**	Substrate *p*-nitrophenyl phosphate, 37 °C						
	Total						
	Serum, men		9.15		4.40	114	The acid phosphatase of serun originates from various source (erythrocytes, thrombocytes, leu cocytes, prostate, bone) which ca be identified by the difference i behaviour towards formol and t tartrate. Serum acid phosphatas determination is important in th diagnosis of prostate carcinoma though in most cases an increase occurs only in the presence of bony metastases. The diagnosis can be established with greater certainty by determining the formol-stable and tartrate-labile fractions, especially the latter. For reviews see the literature[116].
	Serum, women		8.00		2.94	114	
	Plasma, men		5.08		3.54	114	
	Plasma, women		4.41		1.60	114	
	Prostatic						
	Serum, men		1.84		1.80	114	
	Serum, women		1.85		1.58	114	
	Plasma, men		0.32		0.64	114	
	Plasma, women		0.33		0.60	114	
	Substrate phenyl phosphate, 37 °C						
	Formol-stable		4.25			115	
	Tartrate-labile		1.25			115	
	Total		5.5			115	
	Newborn			(3–6)		16	
	1 month			(6.5–11)		16	
	1–3 years			(6.5–11)		16	
	3–10 years			(3.5–9)		16	
	10–16 years			(3–10)		16	

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Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name **Recommended trivial name** In brackets abbreviation and *non-recommended trivial name*	Method	Number	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks (see also text on pages 584–588)
3.1 3 5 5'-Ribonucleotide phosphohydrolase **5'-Nucleotidase**	Colorimetric[117], 37 °C			(2–15)		117	Values in children the same as in adults Like alkaline phosphatase, this enzyme shows a large rise in serum activity in obstructive jaundice[118] and a smaller one in hepatogenic jaundice[119]. Unlike alkaline phosphatase it shows no increase in bone disease[118]
3.1.3.9 D-Glucose-6-phosphate phosphohydrolase **Glucose-6-phosphatase**	Colorimetric[120], 37 °C		8			120	Haemolysis interferes because of the rise in nonspecific phosphatases Serum activity increased in acute hepatitis and chronic liver disease[120].
3 1 4 5 Deoxyribonucleate oligonucleotidohydrolase **Deoxyribonuclease** (DNAase, DNase)	Colorimetric, 37 °C		0 65	(0–1 8)		121	
3 1 4.6 Deoxyribonucleate 3'-nucleotidohydrolase ***Deoxyribonuclease II*** (DNAase II)	Colorimetric, 37 °C		0 56	(0–1.2)		121	
3.2.1 1 α-1,4-Glucan 4-glucanohydrolase **α-Amylase**	Amyloclastic[122], modified, 37 °C	100	1500		615	24	*Haemolysis* interferes because of inhibition of the reaction by haemoglobin. Serum activity is low in the newborn but rises to the adult level during the first year[24]. It is pathologically increased in acute pancreatitis and pancreatic carcinoma, occasionally also in other abdominal conditions, severe renal failure, and mumps It is rather lower in chronic pancreatic insufficiency The most important enzyme in the diagnosis of pancreatic disease For reviews see the literature[123]
3 2.1 31 β-D-Glucuronide glucuronohydrolase **β-Glucuronidase**	Colorimetric (phenolphthalein mono-β-D-glucuronate), 37 °C						Slight haemolysis does not interfere Serum activity increases in the 3rd *trimester of pregnancy* but returns to normal post partum (see page 586) High levels are seen in pre-eclampsia[125] and carcinoma of the pancreatic head, in other forms of carcinoma the rise is smaller[80] Serum activity also increased in pancreatitis and liver damage[80], less so in advanced cirrhosis and disseminated liver
	Men			(0 2–0.55)		16	
	Women			(0 09–0 4)		16	
	Men		0 62		0 15	124	
	Women		0 46		0 12	124	
	Colorimetric (*p*-nitrophenyl β-D-glucuronate), 25 °C						
	Men	52		0 35–1.32		124a	
	Women	53		0 22–0 99		124a	

Blood – Enzymes

Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name **Recommended trivial name** In brackets: abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	s	Reference	Remarks (see also text on pages 584-
3.4.1.1 L-Leucyl-peptide hydrolase **Leucine aminopeptidase** (LAP)	Colorimetric (substrate L-leucyl-β-naphthylamide), 37 °C			(15–50)		16	Slight haemolysis does not fere. Values are somewhat lo women, though some work regard the difference as cli insignificant and others[13 found no difference. Serum a greatly increased in pregnan page 586) and in biliary obst of extra- or intrahepatic orig increase in carcinoma of the p atic head in the absence of obstruction and liver metasta Slight increase in inflammato disease and acute pancreatitis
	Colorimetric (substrate L-leucylglycine), 37 °C	82	16.4		0.67	126	
– [Oxytocin-cleaving aminoacylpeptidase] (Oxytocinase)	Colorimetric (substrate L-cystine-bis-β-naphthyl-amide[132] or L-cystine-bis-*p*-nitroanilide[133])						Serum activity increased times in pregnancy (see page The cystine aminopeptidase a of normal serum probably de on the leucine aminopeptid tivity[134].
3.4.1.3 Amino-acyl-dipeptide hydrolase **Aminopeptidase** (Aminotripeptidase)	Colorimetric (substrate glycylglycylglycine), 37 °C	39	64.7		4.2	128	
3.4.4.1 **Pepsin**	Colorimetric (substrate beef haemoglobin), 37 °C	45	1.72		0.91	135	Formed from pepsinogen. S activity rather higher in men in women[137]. It is low or abs gastric atrophy, increased i presence of duodenal ulcers[13
	Colorimetric (substrate beef haemoglobin), 37 °C						
	1 week		2.76	(0.60–8.26)		136	
	3 weeks–6 years		2.41	(1.05–3.08)		136	
3.4.4.4 **Trypsin**							The serum contains no active sin[139]. The trypsin-inhibitin pacity of 1 ml of serum is suff to inhibit on the average 1 r trypsin.
3.4.4.15 **Renin**							Formed in the juxtaglome apparatus of the kidneys an leased into the plasma, wher involved in the formation of a tensin from angiotensinogen pages 740–741).
3.5.3.1 L-Arginine amidinohydrolase **Arginase**	Colorimetric[140], 37 °C......			(0–12)		16	Haemolysis interferes becau the high activity of this enzy the erythrocytes. Serum ac increased in acute and chroni jury to the liver parenchyma increase in obstructive jaundic [141].
3.5.4.3 Guanine aminohydrolase **Guanine deaminase** (Guanase)	Optical[142], 37 °C			0–3		143	Haemolysis does not interfere rum activity increased in liver age.

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Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number *Systematic name* ecommended trivial name ı brackets abbreviation and n-recommended trivial name	Method	Number	Mean	*95% range* (extreme range in brackets)	*s*	Reference	Remarks (see also text on pages 584–588)
4 4							
enosine aminohydrolase **enosine deaminase**	Colorimetric[144], 25 °C	70	2 6	(1 4–4.7)	0 54	145	Haemolysis interferes because of the activity of this enzyme in the erythrocytes Serum activity increased in liver disease, as also in haemoblastosis, reticulosis and acute renal disease
..2 7							
tose-1-phosphate ehyde-lyase **tose-1-phosphate lolase** hosphofructaldolase [PFA], lolase)	Optical[146], modified, 25 °C	18	1 0			6	*Activity of this enzyme in the liver* far exceeds that in other organs, so that an increase in the serum activity is specific for liver disease Serum activity is high in acute hepatitis, less so in chronic liver disease and obstructive jaundice[147]
1.2.13							
uctose-1,6-diphosphate glyceraldehyde-3 phos- iate-lyase **ructosediphosphate dolase** Aldolase [ALD], ymohexase)	Colorimetric[148], 38 °C	115	4 4	(2 2–7 4)		148	Haemolysis interferes because of the activity of this enzyme in the erythrocytes The serum activity rises to a maximum on the 3rd day of life and then falls again to the cord blood value within 3 weeks[16] It is higher in children than in adults[10 16 151] (but see also STAVE[19]) Physical effort results in a moderate increase in serum activity[152] Determination of the serum activity is diagnostically useful in diseases of the skeletal musculature, heart muscle and liver. Increased particularly in muscular dystrophy of DUCHENNE type, often also in the patient's mother, brothers and sisters[153] For reviews see the literature[20]
	Colorimetric[149], modified, 37 °C	21	3 3	(1 8–4.9)		149	
	Optical[42], modified, 25 °C	23	2.7	(1–9 7)		5	
	Optical[42], 25 °C	48	1 8		0 65	6	
	Optical[42], 25 °C blood donors	100	6 4		2 4	10	
	Optical[42], 25 °C	30	5 0		2.5	30	
	Colorimetric[150], 37 °C						
	Adults		3 2		0 4	151	
	Children		6 4		0 5	151	
	Colorimetric, 37 °C						
	Cord blood		9 0	(4.0–17 5)		16	
	1 year		17 5			16	
	2 years		15 2			16	
	6 years		12 0			16	
	12 years		8.7			16	
	18 years		6 6			16	
	Optical[42], 25 °C						
	Infants	50	5 3		1.3	10	
	Children	43	3 6		1.5	10	
	Optical[42], modified, 25 °C						
	Premature infants	25	7.1			19	
	Newborn	18	6 4		2 9	19	
	Infants	54	3 5		1 5	19	
	Children	45	2 4		0 7	19	
4 2 1 2							
L-Malate hydro-lyase **Fumarate hydratase**	Optical[154], 37 °C			Not detectable		155	Serum activity slightly increased in hepatitis[156] No definite increase in carcinoma, even in the late stage[30]
(Fumarase)	Optical[154], 37 °C	30		(0–0 7)		30	
4 2 1 3							
Citrate (isocitrate) hydro-lyase **Aconitate hydratase** (Aconitase)	Optical[157], 37 °C	30		Not detectable		30	No increase in plasma activity in cardiac infarction, hepatitis or cirrhosis[158]

Enzymes: Normal values in U/l plasma or serum of adults unless otherwise stated (for definition of the unit U see page 584)

EC number Systematic name **Recommended trivial name** In brackets: abbreviation and non-recommended trivial name	Method	Number	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks (see also text on pages 584–58
4.2.1.11 2-Phospho-D-glycerate hydro-lyase **Phosphopyruvate hydratase** (Enolase [ENO])	Optical[42], modified, 25 °C .. Optical[42], 25 °C	15 30	3.1 10.5	(1–6.0)	 3.3	5 30	Serum activity increased in li disease, cardiac infarction and tastatic carcinoma[2,30].
5.3.1.1 D-Glyceraldehyde-3-phosphate ketol-isomerase **Triosephosphate isomerase** (TIM)	Optical[42], 34 °C .... Optical[42], 25 °C .... Optical[42], modified, 25 °C ..	21 30 26	142 42.8 234	 (100–400)	58 15 58	159 30 160	Serum activity increased in vi hepatitis and progressive muscu dystrophy[159,161], also in gener ized neoplastic disease and esp cially liver metastases[160].
5.3.1.6 D-Ribose-5-phosphate ketol-isomerase **Ribosephosphate isomerase** (Phosphoriboisomerase)	Colorimetric[162], 37 °C......	11	58.4	(33.4–90.2)		162	Serum activity increased in liv disease, nephritis and lymphosa coma[162].
5.3.1.9 D-Glucose-6-phosphate ketolisomerase **Glucosephosphate isomerase** (Phosphohexose isomerase [PHI], hexosephosphate isomerase)	Colorimetric[163], 37 °C...... Colorimetric[164], 37 °C Adults .... Cord blood		50.8 46.5	 (13.5–86.0) (45–170)	24.2	30 16 16	Serum activity higher in earl childhood than in adults. Increase in cardiac infarction[165,166], an acute hepatitis[165,167], slightly s in chronic liver disease and obstruc tive jaundice[166,167]. Also increase in leukaemia[168], megaloblasti anaemia[78], muscular dystrophy[151] severe thyrotoxicosis[169] and carci noma[167,169,170].
5.4.2.1 D-Phosphoglycerate 2,3-phosphomutase **Phosphoglycerate phosphomutase** (PGM)	Optical[171], modified, 25 °C..	30		Not detectable		30	No definite changes in serum activity in heart or liver disease or in the presence of tumours[30].

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Lipids (for references see page 602)

	Erythrocytes				Plasma or serum				Remarks
	Mean	95% range	*s*	Reference	Mean	95% range	*s*	Reference	
Total lipids (g/l)	5.10	4.08–6.12	0.51	1	–	3.5–8.5	–	2	See text opposite.
Fatty acids (g/l)*									
Total	2.0	–	–	1	–	1.0–5.0	–	2	See text opposite.
Non-esterified ('free')......	0.08	–	–	3	–	0.10–0.35	–	2	
Cholesterol (g/l)									
Total	1.20	1.02–1.38	0.09	1	–	1.0–3.0	–	2	See text opposite.
Free	–	–	–	–	–	0.3–1.0	–	2	

* 1 mmol (mEq)/l ≈ 0.28 g/l, or 1 g/l ≈ 3.57 mmol (mEq)/l.

(For references see page 602)

	Erythrocytes				Plasma or serum				Remarks
	Mean	95% range	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
osphatides (g/l)	2.98	2.58–3.38	0 20	1	–	1.5–3 5	–	2	See text below.
lglycerides (g/l)	~0.2	–	–	4	–	0.5–2.2	–	3	See text below
e acids (mg/l)									
lhydroxycholanic acid (cholic acid)	..	..	...	...	1 4	(0–3 4)	–	5	The serum bile acid content is normally less than 10 mg/l[6] and is *increased* in diseases resulting in disturbance of bile secretion[7], with values up to 400 mg/l.
hydroxycholanic acids (chenodeoxycholic acid and deoxycholic acid) ..	...	.	...	..	0.8	(0–1 9)	–	5	

otal lipids

[illegible] etrically after suitable extraction[8]

Of the erythrocyte lipids, 90% are contained in the cell mem-ane In the leucocytes they account for 5–10% of the dry sub-ance[10], in the thrombocytes about 15%[11] The thrombocyte ids have a similar composition to the erythrocyte lipids[12] The rum lipids are mostly bound to proteins (α- and β-lipoproteins, e the tables on page 602) For further discussion of the serum pids see the literature[13]

The lipid content of the serum depends on various factors, par-cularly age, sex, race, diet, hormonal balance, stress, climate, hysical exercise and occupation. The serum lipid content is lower birth and in childhood than in adult life, and rises steadily up to e age of about 60 years, it is increased in pregnancy[14] Its relation-up to body weight, constitution and blood pressure has been udied[15] There is a positive correlation between the incidence of herosclerosis and the lipid (or low-density lipoprotein, cholesterol nd glyceride) content of the serum[16,17], though no causal connec-on has been conclusively demonstrated The diet should there-ore be so adjusted as to avoid an excessive rise in the serum lipid ontent.

atty acids

From about 3% up to about 10% of the serum fatty acids are nonesterified[18] they consist in the main of components of glycer-des, phosphatides and cholesteryl esters Small amounts of free atty acids are also present in the erythrocytes Unlike the protein-ound lipids of the other fractions, the free fatty acids of serum are nostly bound loosely as anions to albumin.

The free fatty acid content of the serum rises within a few hours of birth to a level three times as high as that in the cord blood[18] t is rather higher in children before puberty than in adults[19], in regnancy it rises towards term and falls to normal by the second lay post partum[20]

For the fatty acid content of the lipid fractions see the literature[21]

Cholesterol

In the serum about one-third of the cholesterol is in the free state, about two-thirds esterified, some 0 7% consists of dihydro-cholesterol[22] The cholesteryl sulphate content of the serum is less than 5 mg l[23] The ratio of the esterified to the total cholesterol (ester quotient) in the serum is extremely constant, in the thrombo-cytes and leucocytes it varies widely[24] Various colorimetric meth-ods have been developed for the assay of cholesterol, but none is very specific[25], most used are those of SCHOENHEIMER and SPERRY[26], ABELL[27] and ZAK[28]

Like the total lipid content, the cholesterol content of the serum depends on various factors, with the diet and bodily activity playing a particularly important role The serum cholesterol level is affected less by the cholesterol content of the diet – most of the serum

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Serum lipoproteins and their composition[1]

Fraction		Content* (g/l serum)	Density	S_f**	$-S$**	Free electrophoresis (fraction)	COHN fraction (method 10)	Lipoprotein composition: Protein (%)	Lipids (%)	Lipid fraction as percenta[ge] of total lipids: Glycerides	Phosphatides	Cholesteryl esters	Free cholesterol	Nonesterified
Chylomicrons..................		0–0.5	<0.96	10^4–10^5	–	–	I+II	1	99	88	8	3	1	–
β-*Lipoproteins, low-density*	LDF₁	1.5	0.96 –1.006	20–400	>70	α_2	I+II	7	93	56	20	15	8	1
	LDF₂	0.5	1.006–1.019	12–20	40–70	α_2	I+III	11	89	29	26	34	9	1
	LDF₃	3.5	1.019–1.063	0–12***	20–40	β	III	21	79	13	28	48	10	1
α-*Lipoproteins, high-density*	HDL₂	0.5	1.063–1.125	–	4–20	α_1	IV+V	33	67	16	43	31	10	–
	HDL₃	3.0	1.125–1.210	–	0–4	α_1	IV+V	57	43	13	46	29	6	6
Nonesterified fatty acids-albumin ..		40.0	–	–	–	–	V	99	1	0	0	0	0	10

[1] OLSON and VESTER, *Physiol.Rev.*, 40, 677 (1960).
* Average post-absorptive values for a healthy, well-nourished man aged 40 years.
** S_f = SVEDBERG flotation units ($-S \times 10^{-13}$ s) at a density of 1.063 and t = 26 °C; $-S$ = SVEDBERG flotation units at a density of 1.21 and t = 26 °C.
*** Fractions 0–2 are high-density lipoproteins (HDL₁).

Serum lipoprotein concentrations at various ages (g/l)[1]

Age	Number	S_f 100–400 Mean	s	S_f 20–100 Mean	s	S_f 12–20 Mean	s	S_f 0–12 Mean	s	HDL₁ Mean	s	HDL₂ Mean	s	HDL₃ Mean	s
Men															
17–29	585	0.37	0.43	0.75	0.41	0.40	0.21	3.22	0.86	0.23	0.07	0.37	0.28	2.17	0.40
30–39	834	0.51	0.64	0.91	0.54	0.51	0.23	3.55	0.84	0.24	0.15	0.36	0.28	2.19	0.42
40–49	399	0.66	0.91	1.07	0.66	0.57	0.23	3.80	0.84	0.25	0.15	0.37	0.28	2.26	0.50
50–65	143	0.58	0.70	1.03	0.58	0.56	0.24	3.83	0.75	0.27	0.22	0.42	0.32	2.24	0.51
Women															
17–29	190	0.09	0.14	0.44	0.29	0.30	0.16	2.83	0.68	0.21	0.07	0.80	0.41	2.28	0.38
30–39	99	0.13	0.17	0.51	0.36	0.41	0.22	3.24	0.86	0.22	0.09	0.81	0.45	2.35	0.38
40–49	37	0.18	0.24	0.65	0.51	0.42	0.21	3.46	0.67	0.23	0.05	0.89	0.53	2.41	0.43
50–65	10	0.32	0.37	0.77	0.48	0.93	0.36	4.37	0.40	0.25	0.07	1.17	0.66	2.70	0.54

[1] LINDGREN and NICHOLS, in PUTNAM, F.W. (Ed.), *The Plasma Proteins*, vol.2, Academic Press, New York, 1960, page 1 (values determined in healthy employees of the University of California Radiation Laboratory, Livermore, Calif.).

Serum lipid concentrations at various ages

	Number	Total lipids (g/l) Mean	Total lipids Extreme range	Total lipids s	Total cholesterol (g/l) Mean	Total cholesterol 95% range (extreme range in brackets)	Total cholesterol s	Free cholesterol (g/l) Mean	Free cholesterol Extreme range	Free cholesterol s	Phosphatides (g/l) Mean	Phosphatides Extreme range	Phosphatides s	Glycerides (g/l) Mean	Glycerides 95% range	Glycerides s	Nonesterified fatty acids (mmol/l) Mean	Nonesterified fatty acids s	Reference
Mothers	36	9.03	–	–	2.60	–	–	0.66	–	–	2.76	–	–	2.28	–	–	–	–	1
Cord blood	21	2.91	–	–	0.75	–	–	0.15	–	–	0.99	–	–	0.69	–	–	–	–	1
Children, 6–8 weeks																			
Milk and meat diet	10	5.74	–	–	1.36	–	–	0.30	–	–	1.77	–	–	1.83	–	–	–	–	1
Vegetable diet	10	3.83	–	–	0.89	–	–	0.17	–	–	1.32	–	–	1.10	–	–	–	–	1
Cord blood	15	3.13	(1.70–4.40)	–	0.74	(0.48–0.98)	–	0.26	(0.19–0.38)	–	1.24	(0.76–1.70)	–	–	–	–	–	–	2
Children, 3–10 days (breast fed)	15	6.08	(4.30–7.60)	–	1.34	(1.10–1.67)	–	0.49	(0.37–0.59)	–	2.07	(1.60–2.60)	–	–	–	–	–	–	2
Children, 1–12 months	37	6.06	(2.40–8.00)	–	1.30	(0.69–1.73)	–	0.40	(0.27–0.66)	–	1.88	(1.22–2.76)	–	–	–	–	–	–	2
Children, 2–14 years	25	8.38	(4.90–10.90)	–	1.88	(1.38–2.42)	–	0.54	(0.39–0.69)	–	2.35	(1.88–2.92)	–	–	–	–	–	–	2
Children, 10–13 years	635	–	–	–	1.54	1.07–2.06	–	–	–	–	–	–	–	0.75	0.33–1.74	–	–	–	3
Men, 16–35 years	62	6.10	–	1.20	1.92	–	0.57	0.64	–	0.19	2.08	–	0.35	0.84	–	0.34	0.750	0.233	4
Women, 16–35 years	29	6.48	–	1.14	1.85	–	0.38	0.58	–	0.18	2.32	–	0.44	0.88	–	–	0.781	0.174	4
Adults, 20–35 years	62	–	–	–	1.78	–	0.26	0.46	–	–	1.78	–	0.23	1.23	–	0.49	0.405	0.081	5
Adults, 45–70 years	30	–	–	–	2.09	–	0.29	0.61	–	–	2.50	–	0.28	–	–	–	–	–	5

	Total lipids* (g/l) Number	2.5%	5%	50%	95%	97.5%	Total cholesterol* (g/l) Number	2.5%	5%	50%	95%	97.5%	Phosphatides* (g/l) Number	2.5%	5%	50%	95%	97.5%	Glycerides* (g/l) Number	2.5%	5%	50%	95%	97.5%	Reference
Men, 15–24 years	150	3.95	4.15	5.82	8.29	8.63	148	1.21	1.42	1.87	2.59	2.78	150	1.45	1.51	1.93	2.57	2.74	142	0.07	0.10	0.98	2.49	2.83	6
Men, 25–34 years	383	4.58	4.81	6.50	9.35	9.95	379	1.47	1.62	2.11	2.94	3.12	383	1.58	1.66	2.15	2.76	2.98	371	0.11	0.22	1.17	2.98	3.77	6
Men, 35–44 years	497	4.93	5.18	7.12	10.91	11.89	494	1.60	1.76	2.37	3.31	3.54	495	1.70	1.82	2.32	3.00	3.18	488	0.20	0.28	1.27	3.43	4.78	6
Men, 45–54 years	499	5.16	5.33	7.44	10.26	11.24	497	1.61	1.77	2.45	3.34	3.49	499	1.77	1.86	2.39	3.09	3.21	491	0.16	0.24	1.32	3.08	3.54	6
Men, 55–64 years	301	5.33	5.55	7.69	10.50	11.73	301	1.75	1.83	2.54	3.28	3.55	303	1.80	1.94	2.43	3.06	3.30	292	0.23	0.31	1.36	3.59	4.07	6

* Sample percentiles
1 Sweeney et al., *Pediatrics*, 27, 765 (1961) (inmates of a Tennessee orphans' home)
2 Rafstedt and Swahn, *Acta paediat (Uppsala)*, 43, 221 (1954), Rafstedt, S., *Acta paediat (Uppsala)*, 44, suppl 102 (1955) (healthy children in Lund, Sweden)
3 Baker et al, *Amer J clin Nutr*, 20, 850 (1967) (schoolchildren in New York City)
4 Svanborg et al, *Acta med scand*, 169, 43 (1961) (healthy adults in Göteborg, Sweden)
5 Eggstein, M., *Klin Wschr*, 43, 1031 (1965), 44, 267 (1966), nonesterified fatty acids from Eggstein et al, *Klin Wschr*, 45, 943 (1967)
6 Hartmann, G., personal communication, 1967 (able-bodied men in Basle, Switzerland).

Fatty acid composition of the serum lipid fractions of adults[1]

	Non-esterified fatty acids	Cholesteryl esters	Phosphatides	Triglycerides
Lipid fraction (g/l serum)	0.29	2.24	2.09	1.73
Fatty acids of lipid fraction (g/l serum)	0.29	0.72	1.11	1.44
Fatty acids (% of total)				
Myristic acid	2.0	1.1	0.9	1.6
Palmitic acid	27.9	12.1	30.7	28.1
Palmitoleic acid	7.2	6.8	3.3	7.6
Stearic acid	14.9	2.6	11.9	3.7
Oleic acid	25.5	18.9	15.1	36.8
Linoleic acid	13.1	47.1	21.5	12.2
Triene acids (C_{18} and C_{20})	0.9	0.9	0.8	0.9
Arachidonic acid	2.4	5.0	8.8	3.1
Pentaene acids (C_{20} and C_{22})	1.2	1.4	2.0	1.2
Hexaene acids (C_{22})...	1.8	1.9	3.1	1.9
Other	3.1	2.2	2.1	2.9

[1] Schrade, W., *Med.u.Ernähr.*, 1, 267 (1960); Schrade et al., *Klin. Wschr.*, 38, 739 (1960) (mean values from 16 healthy subjects aged 18–41 years).
For the fatty acid composition of the lipid fractions in the newborn see Zöllner et al., *Klin. Wschr.*, 44, 380 (1966), in the newborn and infants in relation to diet see Pikaar and Fernandes, *Amer.J.clin.Nutr.*, 19, 194 (1966).

Phosphatides in the plasma and erythrocytes[1]

	Plasma (15 adults*)		Erythrocyt (13 adults	
	Mean	s	Mean	.
Lipid phosphorus (mg/l)	99.8	15.2	139.5	1:
Phosphatides (% of lipid phosphorus)				
Cephalin**	5.0	0.6	42.4	1
Lecithin	68.2	1.7	32.7	2
Sphingomyelin	19.0	1.9	23.1	1
Lysolecithin	7.7	1.5	1.8	(

* Fasting values. In the cord plasma the proportion of lecithin is lov that of the other fractions higher[2].
** In the serum[3] about one-third of the cephalin fraction consist: plasmalogens, in the erythrocytes[4] about one-half.
[1] Phillips, G.B., *J.Lab.clin.Med.*, 59, 357 (1962).
[2] Zöllner et al., *Klin. Wschr.*, 44, 380 (1966).
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Suggested nomenclature of changes in the serum lipid tent[1]

	Designation for an increa in the serum concentrati
Cholesterol	Hypercholesterolaem
Lipid phosphorus..............	Hyperphosphatidaem
Neutral fat	Hyperlipaemia
Free fatty acids	Hyperlipacidaemia
Total lipids	Hyperlipidaemia
Clouding by neutral fat	Lipaemia

[1] Klenk et al., *Clin.chim.Acta*, 7, 446 (1962).

Carbohydrates (for references see page 606)

Glucose, fasting values (mg/l)

	Determined in	Method	Number	Mean	95% range	s	Reference
Pregnancy	Capillary blood	Hagedorn-Jensen	19	931	878–984	26.7	1
		Glucose oxidase	19	867	788–946	39.5	1
Newborn	Cord blood	Hagedorn-Jensen	20	856	790–922	33.2	1
		Glucose oxidase	20	671	588–754	41.5	1
1st hour	Capillary blood	Hagedorn-Jensen	20	558	489–627	34.4	1
		Glucose oxidase	20	263	190–336	36.5	1
6th day	Capillary blood	Hagedorn-Jensen	16	708	653–763	27.5	1
		Glucose oxidase	16	447	381–513	32.8	1
Newborn	Cord blood	Somogyi-Nelson	14	730	392–1068	169	2
1 hour.......	Capillary blood	Somogyi-Nelson	14	626	224–1028	201	2
2 hours	Capillary blood	Somogyi-Nelson	14	589	209–969	190	2
9 hours	Capillary blood	Somogyi-Nelson	14	590	310–870	140	2
24 hours	Capillary blood	Somogyi-Nelson	14	579	301–857	139	2
48 hours	Capillary blood	Somogyi-Nelson	14	591	321–861	135	2
Newborn 1–78 hours ...	Blood	Hagedorn-Jensen	63	841	–	–	3
		Somogyi-Nelson	63	598	–	–	3
Children 1–17 months .	Blood	Hagedorn-Jensen	10	948	–	–	3
		Somogyi-Nelson	10	796	–	–	3

Remarks

Methods. Reduction method: determining 'blood sugar' – instance Hagedorn-Jensen, H man, Folin-Wu, Somogyi-Ne – determine other hexoses (f tose, mannose, galactose), pent glucuronic acid, glutathione, acid, creatine and creatinine, corbic acid and various drug addition to glucose. Aldohex can be determined colorimetri with *o*-toluidine[7,10] or triphe tetrazolium chloride[11]. Most cific are the enzymatic met using either glucose oxidase peroxidase[8,12,13] or hexoki with glucose-6-phosphate dehy genase[13].
Physiological and pathological r tions. After 12 hours fasting glucose level in the capillary bl approximates to that in the ve blood; after glucose intake higher in the capillary and art than in the venous blood. In le cytosis there may be a false app ance of hypoglycaemia owing glycolysis in the leucocytes[14]. concentration of glucose is the s in the serum water and erythro

ilucose, fasting values (mg/l) *(continued)*

	Determined in	Method	Number	Mean	95% range	s	Reference	Remarks (continued)
Children								
2–14 years .	Blood	HAGEDORN-JENSEN	15	933	–	–	3	water The blood glucose level falls during the first hours of life and then rises slowly over the next few days[1 2 15], this hypoglycaemia of the newborn is particularly marked in premature infants[16 17], in poorly nourished children[18] and in children of diabetic mothers[16]. The blood glucose level is pathologically *increased* in diabetes and adrenocortical (CUSHING's syndrome) or pituitary disorders (acromegaly), after administration of ACTH, by an increase in the amount of circulating adrenaline, and in WERNICKE's encephalopathy, it is *decreased* in insulin excess, the dumping syndrome, impairment of adrenocortical (ADDISON's disease) or pituitary function, lesions of the hypothalamus and some liver diseases
		SOMOGYI-NELSON	15	843	–	–	3	
Adults	Blood	HAGEDORN-JENSEN	21	1072	–	–	3	
		SOMOGYI-NELSON	21	1000	–	–	3	
Children								
8–14 years ...	Venous blood	Glucose oxidase	12	800	600–1000	–	4	
Adults ...	Venous plasma	SOMOGYI-NELSON	33	995	819–1171	88	5	
		Glucose oxidase	33	909	751–1067	79	5	
Adults	Venous blood	Glucose oxidase	38	800	668–932	66	6	
Adults . .	Blood	*o*-Toluidine	21	–	630–870	–	7	
Adults . .	Blood	Glucose oxidase	94	810	630–990	90	8	
Birth–29 years .	Capillary blood	HOFFMAN	41	859	683–1035	88	9	
30–49 years .	Capillary blood	HOFFMAN	103	878	650–1106	114	9	
50–69 years ..	Capillary blood	HOFFMAN	155	897	623–1171	137	9	
70 years and over	Capillary blood	HOFFMAN	46	991	665–1317	163	9	
17–45 years	Capillary blood	Hexokinase	199	828	700–950	65 6	12	

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range	s	Reference	
Pentoses (mg/l)					6 6	0 2–13 0	3 2	19	Values from 28 subjects, determined with orcinol
L-Xylulose					1 4	0–5 0	1 8	20	Values from 36 subjects Increased in diabetes
Galactose (mg/l)	15 9	3 4–28 4	6 25	48					Values from 100 subjects, determined enzymatically.
Mesoinositol (mg/l)					10 9	6 7–15 1	2 1	21	Values from 18 subjects, determined enzymatically
Sugar phosphates (µmol/l)		Erythrocytes							
Diphosphoglyceric acid	4420	600–8240	1910	22					
Phosphoenolpyruvic acid	8 8	3 6–14 0	2 6	22					
2 Phosphoglyceric acid	4 3	0 7–7 9	1 8	22					
3-Phosphoglyceric acid	61 2	36 4–86 0	12 4	22					
Glyceraldehyde 3-phosphate	2.6	1 2–4 0	0 7	22					
Dihydroxyacetone phosphate	4 9	0–11 9	3 5	23					
Glucose 6-phosphate	24 8	5 2–44 4	9 8	22					
Fructose 6-phosphate	5 4	3 4–7 4	1 0	22					
Fructose 1,6-diphosphate	4 6	2 6–6 6	1 0	22					
Pentose 5-phosphate	18	0–36	9	23					
Nucleotide pentose	3800	2630–4980	590	23					
Sedoheptulose 1,7-diphosphate	9	–	–	24					
Octulose 1,8-diphosphate	3	–	–	24					
Galactose 1-phosphate (mg/l)								.	Increased in galactosaemia
Cord blood	17	1–33	8	25					
Children, adults	0	0–6	3	25					
Glucuronic acid, total (mg/l)									
(a) Children					65	–	–	26	Values from (b) 56, (c) 44 subjects determined with (a) carbazole, (b, c, d) naphthoresorcinol Component of glycoproteins (see page 606), in serum occurs mainly bound to glycosides, but part is free[29] The serum glucuronic acid level is decreased in the nephrotic syn-
(b) Men					32	19 6–44 4	6 2	27	
(c) Women					32	23–41	4 5	27	
(d)	–	Erythrocytes (0–20)	–	28					

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Glycogen (mg/l)	55	(12–162)	–	31	0	–	–	31	In glycogen storage disease content of the erythrocyte creased[32, 34].
(µg/g haemoglobin)		Erythrocytes:							
Newborn, 1st day	155	(48–361)	–	32					
Children, 1–12 months.....	86	(32–151)	–	32					
Adults	56	(26–105)	–	32					
		Granulocytes:							
($mg/10^9$ cells)	7.5	(4.7–11.9)	–	33					
Heparin (mg/l)	...	...	...	...	–	(1.0–2.4)	–	35	
Protein-bound carbohydrates (glycoproteins) (mg/l)									
Total	...	...	...	...	2739	–	–	36	Various proteins in the seru cytes, leucocytes and thromb tain carbohydrates[38, 39]. Fo hydrate content of the serur teins see page 581. The he serum glycoproteins are ga mannose, the hexosamines ine and glucosamine (in the r
Hexoses	...	...	...	...	1210	1170–1250	21	36	
Hexosamines	...	...	...	...	830	750–910	40	36	
Sialic acid	...	...	...	...	600	526–674	37	36	
Fucose	...	...	...	...	89	77–101	6	36	
Uronic acids	...	...	...	...	2.3	0.8–3.8	0.75	37	

The serum level of protein-bound carbohydrates is the same in men and women[41] (there is an increase towards term in pregnancy[42]); that of sialic acid[41, 43] and hexoses[42, 44] increases with age. The serum sialic acid level in the newborn is lower than in the mother[45, 46] and attains the adult level within 4 months[46]. The serum glycoprotein level is *increased* in accompanied by tissue breakdown, in the collagen diseases, and in in and degenerative disorders. For further discussion of the pathologi in the glycoproteins see the literature[38, 42, 47].

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Non-nitrogenous metabolites (for references see page 608)

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range	s	Reference	
Ethyl alcohol (mg/l)	–	(<1.5)	–	34	...	...	...	...	For colorimetric determination s Shine et al.[35].
Acetaldehyde (mg/l)	2.3	(0.5–4.0)	–	36	...	...	...	...	*Increased* in alcoholic poisoning. detected in the breath when the concentration exceeds 5 mg/l.
Acetoin (mg/l)	0.10	–	–	37					

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
,3-Butylene glycol (mg/l)	1 17	–	–	37					
Glycerol (mg/l)									
(a) Children, 8–14 years....	...	. .	...	...	5.5	0.9–10	–	38	Values from (a) 12, (b) 15, (c) 57
(b) Adults	...	...	. .	...	7 5	2.9–12 1	2 3	39	jects for the free glycerol Glyce mainly present as a component c
(c) Adults	..	.	...	...	11	0–23	6	40	glycerides (see under 'Lipids', page
Volatile acids (mg/l) .. .	17	–	–	1	...	...	...	..	About 25% consists of formic acid, of acetic acid and 0–5% of prop acid
Fatty acids	...	...	...	.	.	.	.	.	See under 'Lipids', page 601
Malic acid (mg/l).... .	4 6	(2 4–7.5)	–	2	0.43	0 19–0 67	0 12	3	Serum values from 14 subjects mined enzymatically Increased in insufficiency
Succinic acid (mg/l) .	.	..		.	5	–	–	4	
Citric acid (mg/l)									
Umbilical vein	16 9	4 3–29 5	6 3	5					Values (a) from 29 fasting subject
Umbilical artery	13 0	8 2–17 8	2.4	5					creases by 4–9 mg/l after a meal
Adults .	–	(13 0–16 7)	–	6	–	(19 2–26.0)	–	6	
(a) Adults .			.		26	(17–31)	–	7	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lactic acid (mg/l)									
(a) Umbilical vein	196	60–332	68	11		.			Values from (a) 14, (b) 69 subjects
(a) Newborn, 1 hour	160	40–280	60	11					ues (b) in arterial blood of fasting
(a) Newborn, 1 day	144	28–260	58	11					jects completely at rest, (c) in ve
(a) Newborn, 2 days	135	41–229	47	11					blood under the usual conditions colorimetric assay see Barker et
(b) Adults	56	42 2–69 8	6 9	12					for enzymatic methods see Olson
(c) Adults	90	68 4–112	10 8	12					Bergmeyer[16]
		Erythrocytes							
	76	32–120	22	13					

The blood lactate level is *increased* by muscular activity and emotional excitement in the newborn (especially in the arterial cord blood)[5 11 17], and towards term in pregnancy[18], often *decreased* in renal insufficiency[9] A syndrome ciated with a high blood lactate level (lactacidosis) has been described[1]

Oxalic acid (mg/l)	–	(2 0–3.2)	–	20	–	(1 4–2 8)	–	20	Values from 15 adults on a normal
Glyoxylic acid					0	–	–	20	
Pyruvic acid (mg/l)									
Umbilical vein	7 1	1 1–13 1	3 0	5	.		.	..	Values from (a) 120, (b) 21 sub values (b) determined enzymatical
(a) Children, 2–13 years	6 73	4 93–8 53	0 90	21					venous blood of fasting subjec complete rest Pyruvic and other
(b) Adults	5 6	1.2–10 0	2 2	22	6 4	2 6–10 2	1.9	22	acids are unstable and should ther be determined in whole blood t than in serum
		Erythrocytes							
	8 2	2 6–13 8	2.8	13					

The blood pyruvate level is high in the newborn and falls during the first days of life[17 23] It is increased by glucose intake, muscular effort and emotional excitement Pathological increases are seen in vitamin B_1 deficiency, respiratory alkalosis, severe cardiovascular disturbances, arsenic and mercury poisc and liver disease For a review see Nordmann and Nordmann[19]

α-Ketoglutaric acid (mg/l)									
Cord blood	2	–	–	6		.	..	.	Values from (a) 120, (b) 40 subjects
(a) Children, 2–13 years	1.36	0 70–2 02	0 33	21					physiological and pathological ch in the blood α ketoglutarate leve
(b) Children, adults	1.3	0 5–2 1	0 4	24					much the same as those in the pyr level
α-Ketoisovaleric acid (mg/l)	1.3	0 9–1 7	0 2	24	.	.	..	...	Values from 40 children and adul

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
α-Ketoisocaproic acid and α-keto-β-methylvaleric acid (mg/l)	3.8	1.8–5.8	1.0	24	...	...	...	...	Values from 40 children a
Oxaloacetic acid (mg/l)	1.2	–	–	25					
Ketone bodies (μmol/l)									
(a) Newborn, < 4 hours	90	(40–180)	–	26	...	...	...	...	Values (a) in capillary bl (b) from 94, (c) from 19 sub lation from values (b) gi acetone or 14.9 mg β-hy acid per litre. Few metho mining ketone bodies are sa Acetoacetic and β-hydroxy can be determined by specif methods (see values below).
(a) Newborn, 2–6 days	670	(90–1900)	–	26					
(a) Children, 1 week–1 year	250	(30–890)	–	26					
(a) Children, 1–2 years	540	(40–2300)	–	26					
(a) Children, 2–6 years	290	(30–1100)	–	26					
(a) Children, 6–15 years	130	(10–540)	–	26					
(b) Adults, fasting	143	5–281	69	27					
(c) Adults, non-fasting	107	0–247	70	27					

25–35% of the blood ketone bodies consist of acetoacetic acid and acetone, 65–75% of β-hydroxybutyric acid[29, 30]. The level is increased by long fasting. For the biochemical basis of ketone-body formation see the literature[31].

The ketone bodies of blood are pathologically *increased* in untreat glycogen storage disease, alkalosis, CUSHING's syndrome and unde of growth hormone.

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Acetone (mg/l)									
(a) Children, 1–3 years	...	...	...	...	12	(0–37)	–	28	Values from (a) 50, (b) 47, jects.
(b) Children, 10–15 years	...	...	...	...	9	(0–34)	–	28	
(c) Adults	...	...	...	...	2.9	2.3–3.5	0.3	32	
Acetoacetic acid (mg/l)*									
(a) Children, 1–3 years	...	...	...	...	6	(0–32)	–	28	Values from (a) 45, (b) 43, (c) (e) 7 subjects; values (d, e) d enzymatically.
(b) Children, 10–15 years	...	...	...	...	3	(0–28)	–	28	
(c) Adults	–	(0.55–2.6)	–	33	–	(0.80–2.8)	–	33	
(d) Adults, non-fasting	1.7	(0.5–4.6)	–	30					
(e) Adults, fasting	3.2	(1.8–7.8)	–	30					
β-Hydroxybutyric acid (mg/l)**									
(a) Children, 1–3 years	...	...	...	...	13	(0–35)	–	28	Values from (a) 11, (b) 17, (7 subjects; values (c, d) deter zymatically.
(b) Children, 10–15 years	...	...	...	...	9	(0–25)	–	28	
(c) Adults, non-fasting	3.7	(1.4–9.9)	–	30					
(d) Adults, fasting	9.4	(5.8–17.1)	–	30					
Lipoic acid (μg/l)	...	...	...	...	15.8	8.8–22.8	3.5	41	Values from 10 subjects.

* 1 mg/l = 9.8 μmol/l. ** 1 mg/l = 9.6 μmol/l.

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Blood – Vitamins

(For references see page 611)

	Whole blood: Mean	Whole blood: 95% range (extreme range in brackets)	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range (extreme range in brackets)	Plasma or serum: s	Plasma or serum: Reference	Remarks
Carotenes (μg/l)	..	..	..	...	850	(200–1990)	–	1	Values from 133 adults on a d a normal carotene content

The serum carotene level is rather high towards term in pregnancy[2]; in cord blood it is about 25% of that in the maternal blood[3]. In infants it is often *increased*, probably as a result of the high intake of milk and vegetables for children are within the above normal range[4]

	Whole blood: Mean	Whole blood: 95% range (extreme range in brackets)	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range (extreme range in brackets)	Plasma or serum: s	Plasma or serum: Reference	Remarks
Vitamin A (μg/l)	.	..	...	..	324	(207–471)	–	1	Values from 133 adults on a d a normal carotene and vitamin tent

... A level is abo... 25% lower towards term in pregnancy[2,5] [illegible]

In the serum about 90% of the vitamin A is present as alcohol, the re as ester, almost all is bound to the plasma proteins (see page 457) So the body's reserves of the vitamin are not exhausted, the serum level constant. It is pathologically decreased in infections, in lobular pn vitamin A may disappear completely from the serum[6]

	Whole blood: Mean	Whole blood: 95% range (extreme range in brackets)	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range (extreme range in brackets)	Plasma or serum: s	Plasma or serum: Reference	Remarks
Vitamin D (IU/l)									
Children					–	*(860–2100)*	–	10	Values by biological method (r
Adults					2000	(700–3100)	–	1	In the serum, vitamin D is boun globulins and albumin (see page
Tocopherol (mg/l)									
(a) Cord blood					5.7	(1 0–11.2)	–	8	*Values from (a) 46, (b) 71, (c)* jects by (a) method of Na Magar[10] and (b, c) method of *et al.*[11]
(b) Men					10.6	5 6–15 6	2 5	8	
(c) Women					10.4	5 0–15 8	2 7	8	

The serum tocopherol is 88% α-, the remainder β and γ-tocopherol[12] The serum level is increased in pregnancy[13], it is decreased in the newborn and various tocopherol-deficiency states, particularly cystic pancreatic fibrosis (see page 466)[14] Breast fed infants have higher serum levels than those o milk[14]

	Whole blood: Mean	Whole blood: 95% range (extreme range in brackets)	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range (extreme range in brackets)	Plasma or serum: s	Plasma or serum: Reference	Remarks
Ubiquinone (mg/l)					0 73	(0 40–1 15)	–	16	The serum contains ubiquinone-
Thiamine (μg/l)									
(a) Total	28	(20–75)	–	17	21	(18–62)	–	17	Values (a) from 138 (whole blo 128 (*serum*) subjects determined *romonas danica*, values (b) from jects determined by *Ochromonas malhamensis*, values (c) from 11 subj thiochrome method Total thia determined after hydrolysis of amine *pyrophosphate*
(b) Total	–	(20–41)	–	18	–	(3–15)	–	18	
(c) Total	–	(40–70)	–	19					
(c) Free	–	(6 5–11 4)	–	19					

The thiamine of the erythrocytes and leucocytes is mainly pyrophosphate (see page 470) The serum thiamine level is lower towards term in pregnancy (mean 11 5 μg/l), higher in the newborn (mean 55 μg/l)[20] The fall in the erythrocyte thiamine pyrophosphate level in thiamine deficiency is m of diagnostically in the transketolase test (see page 470) The blood th level is low in insulin dependent diabetics[21],

	Whole blood: Mean	Whole blood: 95% range (extreme range in brackets)	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range (extreme range in brackets)	Plasma or serum: s	Plasma or serum: Reference	Remarks
Riboflavin (μg/l)									
(a) Total	66 8	(49–104)	–	22					Values (a) from 18 men and 42 by the lumiflavin method, val from 13, (c, d) from 12 subjects photometric analysis, values (e 8 subjects by using *Lactobacillus c* In cord blood serum the level riboflavin is 4 times, that of FMN that of FAD half, *as high as in the* nal serum[25] A lowered eryt riboflavin level indicates ribofla ficiency[26] (see page 473)
(a) As FMN and FAD	55 1	(43–71)	–	22	.		..	.	
(b) Total			.	.	32	(26–37)		23	
(b) As FAD					24	(18–30)		23	
(b) Free and as FMN					8	(3–13)	–	23	
(c)	224	Erythrocytes (180–262)	–	23					
(d)	2520	Leucocytes (2270–2930)	–	23					
(e) (μg/10⁹ cells)	0 62	0 18–1 06	0 22	24					

	Whole blood: Mean	Whole blood: 95% range (extreme range in brackets)	Whole blood: s	Whole blood: Reference	Plasma or serum: Mean	Plasma or serum: 95% range (extreme range in brackets)	Plasma or serum: s	Plasma or serum: Reference	Remarks
Vitamin B_6									
Total activity (μg/l)									
(a)	37	(20–45)	–	27	44	(30–80)	–	27	Values determined by means of *Tetrahymena pyriformis*, (b, c) *Saccharomyces carlsbergensis*, values from (b) 30 subjects For methods of determining vita see the literature[29,30] and page
(b) Men	19.2	(6 8–77)	–	28					
(c) Women	17 7	(4.4–76)	–	28					
(a)	20	Erythrocytes (13–31)	–	27					

The vitamin B_6 activity of the blood is probably mainly due to pyridoxal phosphate pyridoxol appears to be absent[31] The blood level is rather low during pregnancy[28,32], in the cord blood the concentration is about 4 times the maternal blood[28]

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Pyridoxal phosphate (µg/l)									
(a) Birth–1 year	...	...	...	...	16.3	(6.5–57.1)	16.7	33	Values from (a) 14, (b) 13, (c) 11, ((e) 40 subjects by the tyrosine deca ylase method.
(b) 20–29 years	...	...	...	...	11.3	(3.8–21.6)	5.7	33	
(c) 30–59 years	...	...	...	...	7.1	(2.4–12.4)	3.0	33	
(d) 60 years and over	...	...	...	...	3.4	(0–13.5)	3.0	33	
(e) (µg/10^9 cells)	–	Leucocytes: (0.14–0.36)	–	34					
Pyridoxic acid (µg/l)	–	(100–130)	–	31	...	...	...	...	Values from 3 subjects determined rometrically.
Nicotinic acid (mg/l)									
(a)	–	(3.9–9.6)	–	29	–	(0.016–0.05)	–	29	Values from (a) 28, (b) 39, (c) 46 jects by means of (a) *Tetrahymena formis*, (b, c) *Lactobacillus arabinosus*. In whole blood the nicotinic acid oc almost exclusively as nicotinamide nucleotides (NAD and NADP) in cells (in the erythrocytes 60–90 mg/ the leucocytes 88 mg/l, expresse NAD[36]).
(b) Men	6.55	5.32–7.78	0.615	35					
(c) Women	6.05	4.59–7.51	0.730	36					
1-Methylnicotinamide (mg/l)	...	...	...	...	0.017	–	–	36	After ingestion of nicotinamide the tabolites 1-methyl-2-pyridone-5-carb ylamide and 1 methyl-4-pyridone-5- boxylamide are found in the plasma
Vitamin B_{12} (ng/l)									
(a)	...	...	...	...	611	277–945	167	38	Values from (a) 39, (b) 223, (c) 28, 3, (e) 50 subjects determined by us (a) isotope dilution, (b) *Euglena grac* (c, d) *Ochromonas malhamensis*, (e) *La bacillus leichmannii*. For discussion methods see the literature[29, 43].
(b)	...	...	...	...	356	(100–900)	–	39	
(c)	–	(120–450)	–	18	–	(140–640)	–	18	
(d)	74	Erythrocytes: (59–88)	–	40					
(e)	213	(110–500)	–	41					
(ng/kg)	–	Leucocytes: (500–4300)	–	42					
(ng/10^9 cells)	–	(2.45–6.65)	–	42					

About 80% of the vitamin B_{12} of the serum is not utilizable by micro-organisms unless it is first liberated by heating. This part is bound to α_1- and α_2-globulins[44]. Most of the vitamin B_{12} activity of the serum appears to be due to methylcobalamin[45]. The serum values show a lognormal distribution[46]. The serum level is rather low during pregnancy[47, 48]; in the cord blood it is higher than in the maternal blood[49].

The serum level is pathologically *decreased* in pernicious anaemia, cancer of t stomach, gastric resection, lesions of the small intestine (malabsorpti syndrome), fish-tapeworm carriers and alimentary vitamin B_{12} deficiency (example in vegetarians); it is *increased* in liver and renal diseases, diabetes a leukaemia[39, 43, 46]. Serum values below 100 ng/l are indicative of severe de ciency of the vitamin (megaloblastic anaemia).

	Whole blood mean	Whole blood range	s	Ref.	Plasma mean	Plasma range	s	Ref.	Remarks
Folic acid (µg/l)									
(a)	12.0	(3.0–20.0)	–	50	...	...	...	...	Values from (a–c) 43, (d) 27, (e) 24 su jects determined by means of (a) *Strep coccus faecalis*, (b) *Pediococcus cerevi* (c–e) *Lactobacillus casei*. Only with t latter can 5-methyltetrahydropter glutamic acid, the most important mem ber of the folic acid group in blood, determined (see page 478). For metho of determination see the literature[illegible]
(b)	6.35	(1.5–25.0)	–	50					
(c)	89	(47–149)	–	50	8.2	(3.5–15.0)	–	50	
(d)	327	Erythrocytes: (184–655)	–	51	9.4	(5.2–23.8)	–	51	
(ng/10^9 cells)									
(e)	2.6	–	1.8	52					
(e)	64	Leucocytes: –	42.5	52					

Of the serum folic acid 64% is protein-bound[54].
During pregnancy the serum level is often low[47, 50]; in the cord blood it is higher than in the maternal blood[55], but falls during the first weeks of life[56]. It is pathologically *decreased* in diseases of the small intestine, chronic polyarthritis, myelofibrosis, carcinomatosis and dietary deficiency of the vitamin; values below 3 µg/l indicate severe folic acid deficiency (megaloblast anaemia)[50, 51]. The folic acid content of the leucocytes is increased in my leukaemia[57]. The concentration in the erythrocytes and whole blood is a indication of the amount of the vitamin stored by the body[58].

	Whole blood mean	Whole blood range	s	Ref.	Plasma mean	Plasma range	s	Ref.	Remarks
Unconjugated pterins (µg/l)	–	(27–70) Erythrocytes:	–	18	–	(11–43)	–	18	Determined by means of *Crith* *ticulata*.

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Biotin (ng/l)									
(a) Infants	324	(147–555)	114	71	. .	.	.	. . .	Values from (a) 30, (b) 25, (c) 12 s[…] jects by means of (a, b) *Lactobacillus pl[…] tarum*, (c) *Ochromonas danica*
(b) Adults	258	(120–422)	74	71					
(c)	–	170–279	–	29	–	213–404	–	29	
Pantothenic acid (µg/l)									
(a) Total	–	(230–2075)	–	18	–	(200–1650)	–	18	Values from (a) 28, (b) 30 subjects […] means of *Lactobacillus plantarum*
(b) Total	464	382–546	41	59					
(b) Free	28.7	0–58 7	15	59					

During pregnancy the blood level lies within the above normal range[20, 60], in the newborn the level is about 5 times higher than in the maternal blood[20]

The blood level is *increased* – with reduction of the liver content – in fatty […] acute cirrhotic liver[61], *decreased* in rheumatoid arthritis[62]

	Whole blood				Plasma or serum				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Ascorbic acid (mg/l)									
(a) Men, 20–30 years	5 07	(2 24–8 80)	–	63	4 76	(1 96–8.76)	–	63	Values from (a) 11, (b) 7, (c) 558, (d) […] (e) 50 subjects, values (a–c) determin[…] with 2,4-dinitrophenylhydrazine F[…] methods see Roe et al [65]
(b) Women, 20–30 years	8 84	(5 17–12 8)	–	63	8 97	(6 24–14 1)	–	63	
(c) Children, 10–13 years					6	0–15	–	72	
(µg/10⁸ cells)		Leucocytes							
(d) 18–45 years	350	210–530	–	64					
(e) 60–91 years	134	20–360	–	64					

[illegible]

in women this proportion fluctuates during the menstrual cycle[68] Admin[…] tration of corticosteroids causes dehydroascorbic acid to disappear from t[…] serum[69]

Erythroblasts are all nucleated precursors of the erythrocytes; the term includes the pro-erythroblasts, the erythroblasts proper and the normoblasts. Under physiological conditions the peripheral blood contains only the last-named – and only during the first two days of life. The normoblasts closely resemble the erythrocytes in respect of plasma-staining, haemoglobin content and size. The erythroblasts proper are polychromatic in plasma-staining, the pro-erythroblasts basophile.

By *erythroblastosis* is understood the entry of erythroblasts into the peripheral blood; it is always a sign of increased erythropoiesis and is therefore usually accompanied by reticulocytosis. In the newborn (including premature babies and young infants) they indication of persistence or recurrence of extramedullary bloc mation and at the same time of an abnormal relationship be the intensive erythrocyte formation on the one hand and the lute and relatively small bone-marrow volume at this age c other. Severe erythroblastosis of 50–100–500 or more erythro per 100 leucocytes in the early days of life is almost always a si severe haemolysis due to blood-group incompatibility bet mother and child. In later infancy and childhood the main cau peripheral erythroblastosis are haemolytic anaemia, haemorr anaemia, and occasionally leucosis or cyanotic heart defects.

	Mean	Extreme range	s	Reference	Remarks
Number (per 100 leucocytes)					
Cord blood	3.2	(0–30)	–	1	Method: Counting in GIEMSA-stained blood smears.
Newborn, 1–10 hours	1.6	(0–16)	–	1	
Newborn, 2 days	–	(0–1)	–	1	
Adults	0	–	–	1	

Reference [1] v. BOROVICZÉNY and BALLÓ, *Wien. Z. inn. Med.*, 38, 196 (1957).

Reticulocytes

Synonyms: Vital-granulated erythrocytes, vital-staining erythrocytes, pro-erythrocytes (UNDRITZ[7]), polychromatic erythrocytes.

The reticulocytes are erythrocytes of more than average size and more resistant to haemolysis. There is a sex difference in the reticulocyte count of 3–5 per thousand (see table below). The number of reticulocytes increases with any increase in erythrocyte formation, i.e., continuously in chronic haemolytic or haemorrhagic anaemia, suddenly and persistently for days or weeks in the reparative phase of pernicious anaemia and erythroblastopenia, to a lesser extent also in iron-deficiency anaemia. The number of reticulocytes decreases in aplastic and hypoplastic anaemia, after transfusions and af long-continued administration of oxygen. The extent to which ret ulocytes are released from the bone marrow is in general a meas of the extent of erythrocyte formation.

The wide fluctuations in the data given in the table below normal reticulocyte counts are due to differences in the methods measurement. The better the method of staining, the higher t reticulocyte count obtained (as in counts in smears stained wi brilliant cresol blue).

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Number					
(per μl)	–	10000–50000	–	2	Values for adults by direct measurement. For newborn values see below.
(per 10^3 erythrocytes)	7.5	1.3–13.7	3.1	3	Values for adults. For newborn values see below, for values in children a other adult values see the opposite page. (Values for children in agreement wi WASHBURN[4].)
Diameter (μm)	–	(8.0–9.0)	–	5	1.0–1.5 μm greater than that of erythrocytes (≡ 1.1–1.2 times erythrocyt diameter).
Thickness (μm)	–	(4.5–5.5)	–	6	Erythrocytes 1.8–2.2 μm.
Volume (fl ≡ μm^3)					
Infants	–	(200–230)	–	6	Erythrocytes 5 μm^3.
Adults	–	(250–310)	–	6	Erythrocytes 85 μm^3.

Reticulocyte count during 1st day of life[7]

Hours	Per 10^3 erythrocytes	Per μl
At birth	25.4	126000
2	35.9	168000
4	40.0	190000
6	26.6	148000
[illegible]	25.1	119000

Reticulocyte count in newborn (values per 10^3 erythrocytes)

Days	FANÉN[8]	SEIP[13]	GAIRDNER et al.[15]
1	22	52	37
2	20.4	50	–
3	16.6	52	–
4	10.7	45	27.5
5	5.3	33	–
6	4.8	18	–
7	3.8	13	–
			7.9

Reticulocyte count in childhood (per 10³ erythrocytes[1,4])

Age	Mean	95% range	s
1–24 hours	39 2	–	–
1–7 days	22 3	–	–
7–10 days	10 6	–	–
10–30 days	7 9	0 3–15 5	3 8
1–2 months	12 9	0–27.7	7.4
2–6 months	10 6	0–24 8	7.1
6–12 months	7.5	0–17.3	4.9
1 year	7.5	0–16 3	4 4
2 years	7.1	0–15 1	4 0
3 years	7 2	0–15 4	4 1
4 years	8 1	0–18 1	5 0
5 years	8 2	0–17.2	4 5
6 years	7.5	0–15 5	4 0
7 years	7 6	0 6–14 6	3.5
8 years	6 8	0 4–13 2	3 2
9 years	7.5	0 9–14 1	3.3
10 years	7.6	1 2–14 0	3.2
11–15 years	7.4	0–15 4	4.0

References

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Reticulocyte count in adults (values per 10³ erythrocytes)

	SEIP[3]		WATSON[3]	
	Mean	Extreme range	Mean	95% range
Men and women	15.7	9 6–23.8	7.5	1.3–13 7
Men	13 5	9 6–18 4	6	1 6–10 4
Women	17.3	10 4–23 8	9	2.6–15.4

Maturity of reticulocytes (per 10³ erythrocytes)

Degree	SEIP[3]		NIZET[12]	
	Mean	Extreme range	Mean	Extreme range
I	0 02	0–0.2	0	–
II	1 1	0–2.6	1.6	0–5 6
III	5 0	1 8–10 8	3 6	0 2–12 3
IV	9 5	5 8–12 0	12 5	–

Erythrocytes

(For other physical and chemical data see under 'Blood', pages 557–611, for references see page 616)

	Mean	95% range	s	Reference	Remarks
Erythrocyte count (red blood count, RBC)					See text below and table, page 617
Haematocrit value (Ht) (packed cell volume, PCV)					See text, page 614, and table, page 617
Diameter (µm)					
(a)	8 56	8 14–8 98	0 21	1	Microscopic measurements on erythrocytes of 10 persons (a) individual cel[ls] wet preparations, (b) dry preparations, (c) rouleaux See text, page 614, a[nd] table, page 617
(b)	7 11	6 31–7 91	0 40	1	
(c)	8 70	8 12–9.28	0 29	1	
Thickness (µm)					
(a)	1 9	1 75–2.1	–	2	(a) and (b) calculated from the single cell volume and the cell diameter, (a) w[et] preparations, (b) dry preparations, (c) microscopic measurements on 10 pe[r]sons See also text, page 614
(b)	2.1	1.9–2.3	–	2	
(c)	1 64	1.50–1 78	0 07	1	
Surface area (µm²)	145 0	128–162	8 3	1	Calculated from the cell diameter and cell thickness The total surface area [of] the erythrocytes of an average man is ca 3820 m² or some 2000 times the bo[dy] surface area
	163	–	–	2	
Volume (fl = µm³)	86 1	73 5–98 7	6 3	1	Calculated from the cell diameter and cell thickness See text, pages 614–61[5] and table, page 617
Weight (pg)	96 8	–	7 02	4	Values have lognormal distribution
Haemoglobin (Hb) content					See text, page 615, and table, page 617

Erythrocyte count

Methods

The visual counting methods still used in most laboratories are subject to considerable error, the coefficient of variation in the results given by different methods being 10–15%[3,4]. Automatic counting apparatus is more precise, though this applies properly speaking only to the action of counting The errors associated wi[th]

Counts made with the aid of ^{32}P-tagged erythrocytes have given considerably lower figures for the total numbers of circulating erythrocytes than calculations from the concentration in the peripheral venous blood. The erythrocyte concentration of the peripheral blood therefore represents an absolute value of practical diagnostic use only when the total blood volume is measured at the same time. This is shown clearly for example in the first hours of life, when the erythrocyte count often rises to over one million per microlitre while the total blood volume is reduced.

For details of the various methods of counting see the literature[6].

Physiological characteristics

In the newborn the erythrocyte count fluctuates to a greater extent than at any other time of life, even under constant sampling conditions. It is also dependent on the site from which blood is drawn. During the first days of life the capillary blood has up to half-a-million more erythrocytes than the cord or venous blood[7]. The time at which the cord is clamped has an effect on the count. Immediate clamping prevents the passage of a quarter to one-third of the total blood volume available to the newborn child in the placenta. For this reason the erythrocyte count after a few hours in such children may lie about 1–1½ million per microlitre below the normal level. In the newborn the erythrocyte count rises to a maximum after a few hours since the initially high blood volume is reduced by the passage of blood plasma into the tissues[8]. The erythrocyte count falls steadily from the middle of the first week of life up to the middle of the third month owing to the gradual slowing-down of erythropoiesis. The physiological polyglobulinaemia of the newborn is followed by physiological oligoglobulinaemia in the 3-month child.

During pregnancy the erythrocyte count falls[9]. In general the erythrocyte count is dependent on the partial oxygen pressure of the atmosphere and therefore on the altitude. Thus the Indians of the uplands of Peru show marked polyglobulinaemia, beginning in childhood. A very considerable increase in altitude is thus equivalent to an anoxic stimulus to erythropoiesis, descent from a high altitude (like administration of oxygen) to an inhibition. Emotional effects like anxiety and excitement can result in 'stress erythrocytosis', probably as a result of the movement of plasma into the tissues.

During puberty a sex difference in the erythrocyte count of about half-a-million develops.

Haematocrit value

The haematocrit value is the proportion of the volume of the peripheral venous or capillary whole blood occupied by the erythrocytes. On the body haematocrit see page 554. The haematocrit value is dependent on three factors, namely the erythrocyte count, the mean corpuscular volume (see below) and the plasma volume. Since the ratio between the mean corpuscular haemoglobin (see the opposite page) and the mean corpuscular volume varies between only narrow limits, the haematocrit value has almost the same significance as the haemoglobin content of the whole blood.

Measurement

The haematocrit can be measured by a variety of macro- and micro-methods. The best methods are those using high-speed haematocrit centrifuges and microhaematocrit capillaries[10]. The haematocrit value depends on the speed of the centrifuge, the time of centrifuging and the viscosity of the blood. The amount of plasma trapped between the packed erythrocytes is 1–9%, depending on the method[11]; the proportion after centrifuging at 14 000 g_n for 40 minutes is only 0.45%[12].

See also the literature on haematocrit measurement[13].

Physiological characteristics

By its nature the haematocrit varies in a manner similar to the erythrocyte count in newborn children; thus it is dependent on the time the cord is clamped[14], rises during the first hours of life and falls up to the third month. From this time onwards, however, it behaves differently to the erythrocyte count. Whereas the latter remains more or less constant or rises slightly, the haematocrit falls somewhat because the newly-formed erythrocytes are low in haemoglobin and therefore smaller in volume. The haematocrit also resembles the erythrocyte count in respect of sex difference, behaviour during pregnancy and dependence on partial oxygen pressure of the atmosphere.

Erythrocyte diameter

Measurement

Two basically different methods are used to measure the erythrocyte diameter, micrometry and halometry[15]. The latter r od is simple, time-saving and adequate for routine use. Mea ment on blood smears or on optical projections of smears hav advantage that the distribution as well as the mean value is obtai as in blood-volume measurements the former may be of diagn importance. Distribution values, however, should be based on surements on at least 1500–2000 cells[16].

On methods of measurement see also the literature[17].

Physiological characteristics

In the newborn the erythrocyte diameter is likewise high, th unlike the erythrocyte count it continues to fall not only up to third month of life but, as a result of the formation of new eryt cytes low in haemoglobin, up to the end of the first year. The v may fall to a mean value of less than 7 µm.

Pathological characteristics

In pernicious and similar anaemias the erythrocyte diamete high and shows a particularly wide variance. It is fairly high aplastic anaemia, low in iron-deficiency and sideroachrestic ar mias and spherocytosis; in the latter condition a particularly imp tant characteristic is the normal erythrocyte volume.

Numerical eccentricity

Deviation of the shape of the erythrocytes from the truly spheri is expressed as either the axis coefficient K or the numerical ecc tricity ε as follows:

$$K = 1 - \frac{b}{a}; \quad \varepsilon = \sqrt{1 - \left(\frac{b}{a}\right)^2}$$

where a = the larger, b = the smaller diameter. For the determin tion of these values by nomogram see v. Boroviczény[18]. Normal 74.4% of the erythrocytes are spherical, 14.9% non-spherical, 8.2 elliptical and 2.5% grossly elliptical.

Predominance of regularly oval forms is known as elliptocytosi and is a dominant inheritable anomaly of no clinical significance i which all erythrocytes are similar in appearance. Symptomat elliptocytosis of varying morphological and numerical degrees c severity occurs, usually associated with poikilocytosis, in pernicio and similar anaemias, occasionally in leukaemia and rarely in sever infections.

Morphological variations

Poikilocytes are erythrocytes of irregular shape and have a extremely wide range of size. Usually they indicate a disturbanc of erythropoiesis and are probably formed by the extrusion of mass of erythroblastic or normoblastic plasma.

Round cells (spherocytes), basket cells, target cells and sickle cell are mostly phenotypic manifestations of haemolytic anaemia due to metabolic disturbances.

Erythrocyte thickness

The thickness of an erythrocyte is an arbitrary dimension since the erythrocyte is not a true rotation ellipsoid but a disk with bilateral indentations. It is of significance only when showing extreme deviations, namely in spherocytosis of hereditary origin and in phenocopy. During haemolysis the thickness increases to 4–5 µm while the volume remains constant; this results in a lowering of the osmotic resistance of the cell. In iron-deficiency and sideroachrestic anaemias the thickness of the erythrocytes is less than 1.5 µm, so that there is an increase in the osmotic resistance.

Measurement

By direct microscopic measurement or calculation from the erythrocyte volume (mean corpuscular volume) by dividing by the square of the radius × π.

Mean corpuscular volume (MCV)

In contrast to the erythrocyte count and haematocrit, which are dependent on various factors, the mean corpuscular volume is an absolute quantity, i.e., it has an individual though almost const

.ue Measured values are of course mean values and like other ological data exhibit variance With the aid of modern automatic ythrocyte counting instruments it is possible to obtain distribu- on curves of the mean corpuscular volume In the diagnosis of aemia such curves are capable of giving even more information an the itself very useful mean corpuscular volume. Thus in aplas- ;, hypoplastic and especially pernicious and similar anaemias the ean corpuscular volume is high, whereas in iron-deficiency and deroachrestic anaemias it is low, A high mean corpuscular volume n be simulated by a high reticulocyte count since the mean retic- ocyte volume is three times greater than the mean corpuscular olume Macrocytic haemolytic anaemia usually consists of normo- ytic anaemia accompanied by reticulocytosis The high mean cor- uscular volume of the newborn is also partly a result of the rela- vely high reticulocyte count.

leasurement

The mean corpuscular volume is calculated by dividing the hae- natocrit value (in litres per litre) by the number of erythrocytes in litre of whole blood The normal range so calculated is 80–90 fl = μm³)

Mean corpuscular haemoglobin concentration (MCHC)

[illegible]

under pathological conditions there is little variation, so that true diminutions of concentration by 30%, such as are found in extreme iron deficiency, are of considerable diagnostic significance

Measurement

The mean corpuscular haemoglobin concentration (in grammes per litre erythrocytes) is calculated by dividing the haemoglobin concentration of the whole blood (in grammes per litre) by the haematocrit value (in litres per litre)

The sole *physiological characteristic* is the fairly high value at birth, this falls to normal by the end of the first month of life

Mean corpuscular haemoglobin (MCH, Hb$_E$)

Like the mean corpuscular volume, the mean corpuscular haemo- globin (mean haemoglobin content of a single erythrocyte) is a real [illegible]

below 30 pg is known as hypochromia and is characteristic of iron- deficiency and sideroachrestic anaemias

Measurement

The mean corpuscular haemoglobin is calculated by dividing the haemoglobin concentration of the whole blood (in grammes per litre) by the number of erythrocytes in 1 litre The normal value is 30–32 pg (pg = 10^{-12} g)

Physiological characteristics

The mean corpuscular haemoglobin is likewise high in the new- born and undergoes no change during the first day of life It then falls to normal by the third month and to moderately hypochromic [illegible]

The colour index must be corrected by several factors if it is to the same information as the mean corpuscular haemoglobin.

Haemoglobin content of the whole blood

The haemoglobin content of the whole blood is the mean puscular haemoglobin multiplied by the number of erythrocy the volume unit used For this reason it rises and falls both wit [illegible]

Measurement

The recommended standard method is that of photometri [illegible]

Physiological characteristics

The haemoglobin content is subject to much the same variatic the erythrocyte count (pages 613–614) and haematocrit value (614), particularly the latter Thus cord blood contains about 16 venous blood on the first day of life about 182 g/l and cap [illegible]

puberty[9, 44].

During pregnancy the haemoglobin content falls to a mini of 120 g/l in the 30th–35th weeks Lowered and increased p oxygen pressures cause respectively an increase and decrease c haemoglobin content, which in this respect behaves like the ery cyte count[9, 26]

Since the haemoglobin content of the [illegible]

Foetal haemoglobin

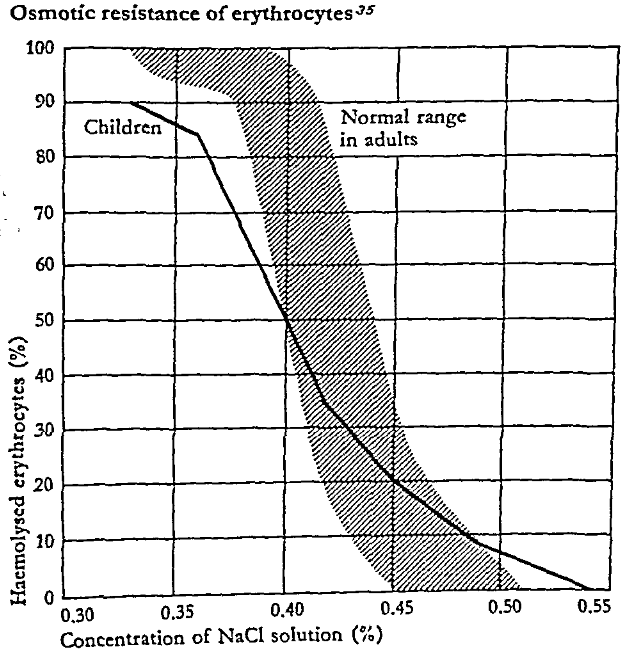
The blood of the very early foetus [illegible]

Erythrocytes

(For other physical and chemical data see under 'Blood', pages 557–611)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Lifetime (days)					
(a) Premature infants	–	(70–90)	–	27	Measurement: (a) and (b) by ASHBY's differential agglutination methoc and (d) with ^{15}N-glycine. The best method is that using ^{32}P-di-isopı fluorophosphate; for details of methods see the literature[29, 30]. A lifetin 120 days corresponds to an erythrocyte turnover of 0.83% per day. Pa logical changes in the lifetime are exclusively reductions[29].
(b) Adults	117	(110–135)	–	5	
(c) Men	120	–	–	28	
(d) Women	109	–	–	28	
Half-life (days)					
Premature infants	16	–	–	27	Measured by means of ^{51}Cr-tagged erythrocytes. In adults the half-life amo to about a quarter of the mean lifetime.
Newborn	24	–	–	27	
Infants, 3 months	28	–	–	27	
Adults	29	(25–40)	–	29	
Osmotic resistance (concentration [%] of the NaCl solution used)					
(a) *Cord blood*					Measured on (a) 16, (b) 14 and (c) 18 subjects. For details of methods see literature[5, 32]; the results are affected by the temperature, nature of the a coagulant used, pH value of the haemolysing solution and bilirubin cont of the blood. Complete haemolysis of the erythrocytes occurs in 0.33–0.3 NaCl solution (see diagram below). The more nearly spherical the eryth cytes, the lower the osmotic resistance[5, 32, 33]. Spherocytes are therefore m readily haemolysed, whereas the thinner erythrocytes are more resista Young mature erythrocytes are more resistant in hypotonic media than erythrocytes[34]. Erythrocytes from venous blood have a lower resistance tl those from arterial blood[35]. *Pathological changes*[5, 32]. Markedly reduced in congenital haemolytic jaund and occasionally in haemolytic jaundice due to the presence of abnormal aı bodies[36], increased in polycythaemia vera, thalassaemia major (resistance i creased up to a NaCl concentration of 0.03%) and in sickle-cell and hyp chromic anaemias.
5% haemolysis	0.502	0.46–0.55	0.022	31	
50% haemolysis	0.422	0.38–0.46	0.021	31	
(b) Newborn, 2–5 days					
5% haemolysis	0.474	0.34–0.51	0.019	31	
50% haemolysis	0.395	0.36–0.43	0.016	31	
(c) Adults					
5% haemolysis	0.475	0.45–0.50	0.012	31	
50% haemolysis	0.424	0.40–0.44	0.010	31	
Metabolism (μmol per 10^{11} erythrocytes)					
O_2 uptake per hour	2.7	0–5.5	1.4	37	
CO_2 formation per hour	2.5	0.3–4.7	1.1	37	
Pyruvate formation per hour	1.9	1.1–2.7	0.4	37	
Lactate formation per hour	38.4	26.6–50.2	5.9	37	

Osmotic resistance of erythrocytes[35]



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(For other physical and chemical data see under 'Blood', pages 557–611)

Age	Reference	Erythrocyte count (millions/µl) Mean	Erythrocyte count 95% range	Haematocrit value (l/l) Mean	Haematocrit 95% range (extreme range in brackets)	Erythrocyte Ø (µm) Mean	Mean corpuscular volume (fl) Mean	MCV 95% range (extreme range in brackets)	Haemoglobin g/l whole blood Mean	g/l whole blood 95% range (extreme range in brackets)	g/l erythrocytes Mean	g/l erythrocytes 95% range (extreme range in brackets)	pg per single erythrocyte Mean	pg 95% range (extreme range in brackets)
1 day	1	5.6	[illegible]	0.561	–	8.6	106	–	212	(177–265)	378	–	38	–
... ck	1	5.3	[illegible]	0.527	–	–	101	–	196	(162–255)	372	–	37	–
... eks	1	5.1	[illegible]	0.496	–		96	–	180	(145–242)	363	–	35	–
... eks	1	4.9	[illegible]	0.466	–	8.1	93	–	166	(132–230)	356	–	34	–
... eks	1	4.7	[illegible]	0.446	–		91	–	156	(120–218)	350	–	33	–
...nths	1	4.5	[illegible]	0.389	–		85	–	133	(108–180)	342	–	30	–
...nths	1	4.5	[illegible]	0.365	–	7.7	79	–	124	(102–150)	340	–	27	–
...nths	1	4.6	[illegible]	0.362	–		78	–	123	(100–150)	340	–	27	–
...nths	1	4.6	[illegible]	0.358	–		77	–	121	(98–150)	338	–	26	–
...onths	1	4.6	[illegible]	0.355	–	7.4	77	–	119	(84–149)	335	–	26	–
...onths	1	4.6	[illegible]	0.352	–		77	–	116	(90–146)	330	–	25	–
...rs	1	4.7	[illegible]	0.355	–	7.3	78	–	117	(92–155)	330	–	25	–
...rs	1	4.7	[illegible]	0.371	–		80	–	126	(96–155)	340	–	27	–
...rs	1	4.7	[illegible]	0.379	–		80	–	127	(100–155)	335	–	27	–
...rs	1	4.7	[illegible]	0.389	–	7.4	80	–	129	(103–155)	332	–	27	–
...ars	1	4.8	[illegible]	0.390	–		80	–	130	(107–155)	333	–	27	–
...ars	1	4.8	[illegible]	0.396	–		81	–	134	(110–165)	338	–	28	–
..., 14 years and over	1	5.4	[illegible]	0.47	0.40–0.54	7.5	87	–	158	140–180	335	–	29	–
...es, 14 years and over	1	4.8	[illegible]	0.42	0.37–0.47	7.5	87	–	139	115–160	335	–	29	–
...	2	–	–	0.368	0.332–0.404	–	79	72–86	123	122–124	–	–	26.3	23.5–29.1
...	2	–	–	0.376	0.340–0.412	–	80	73–87	125	124–126	–	–	27.2	24.4–30.0
...ars	2	–	–	0.377	0.341–0.413	–	81	74–88	128	127–129	–	–	27.5	24.7–30.3
...ars	2	–	–	0.389	0.353–0.425	–	83	76–90	134	133–135	–	–	28.8	26.0–31.6
...ears	2	–	–	0.401	0.365–0.437	–	84	77–91	140	139–141	–	–	29.4	26.6–32.2
...	3	5.2	4.4–6.0	0.46	0.41–0.51	–	88	80–96	150	130–170	330	310–350	29	26–32
...d women	4	–	–	0.481	0.386–0.576	–	–	–	159	134–173	328	299–357	–	–
... 10–20 years	5	4...	[illegible]	0.460	(0.37–0.54)	–	97	(82–107)	146	(121–172)	319	(233–368)	30.7	(28–35)
...–40 years	5	5...	[illegible]	0.479	(0.41–0.55)	–	96	(83–110)	158	(133–182)	331	(291–361)	31.4	(27–38)
...ver 40 years	5	5...	[illegible]	0.463	(0.41–0.52)	–	93	(87–103)	156	(141–170)	336	(308–358)	31.2	(29–36)
..., 10–20 years	5	4...	[illegible]	0.436	(0.38–0.50)	–	98	(77–116)	139	(120–164)	320	(283–368)	31.1	(26–36)
..., 20–40 years	5	4...	[illegible]	0.429	(0.35–0.49)	–	95	(88–109)	141	(118–175)	329	(296–356)	31.2	(28–34)
..., over 40 years	5	4...	[illegible]	0.443	(0.40–0.52)	–	100	(92–117)	139	(127–163)	319	(270–360)	31.9	(30–35)
Men at sea level	6	5...	[illegible]	0.468	–	7.5	91	–	160	(140–183)	341	–	31	–
Men at 4540 m	6	6...	[illegible]	0.599	–	7.7	97.5	–	208	(181–254)	347	–	34	–

* When not otherwise stated, the values are for pers... between sea level and 200 m. The values from DITTMER ... have been summarized from earlier publications in the ... of BETKE et al [2] and DITTRICH[4] derive from studies ... those of GREENDYKE et al.[3] from studies in the USA, the ... studies in Denmark (in references[2–5] haemoglobin wa... the haemoglobin cyanide method), the values of Hu... from studies in the Andes (at sea level [Lima] and at 454... In recent years other normal values have been publishe... (for age groups between 19 and 93 years), in USA[8] ... between 12 and 17 years), in Japan[9] (for adults) and in Turkey[10] (for adults). For erythrocyte data during pregnancy see HOLLY[11] and page 691.

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Leucocytes

(For other physical and chemical data see under 'Blood', pages 557–611; for references see page 620)

	Mean	95% range	s	Reference	Remarks
,eucocyte count .... (white blood count, WBC)	...	...	...	...	See text below and table opposite.
,eucocytocrit (ml/l) .... (leucocyte packing volume)	~2.5	...	...	...	Proportion of volume of the whole blood occupied by the leucocytes; culated from the leucocyte count and mean leucocyte volume.
)iameter..................	...	...	...	...	
'olume..................	...	...	...	...	

	Diameter[1] (μm)	Volume[2] (μm^3 [= fl]
Neutrophils	10–15	450
Eosinophils	10–15	450
Basophils	10–15	450
Lymphocytes	7–18	230
Monocytes	12–20	470
Neutrophil myelocytes	12–18	–

	Mean	95% range	s	Reference	Remarks
Ialf-life (hours)					
;ranulocytes..............	6.6	3.8–9.4	1.4	3	Measured on 45 men by the ^{32}P-di-isopropyl fluorophosphate (DFP) meth
)smotic resistance........	...	...	...	...	After 6 minutes' exposure to 0.2% NaCl solution 55–75% of the leucocy remain unchanged[4]; mononuclear cells are less resistant than granulocyt The resistance increases with age. It is increased in inflammatory leucocyto as a result of the increased number of young cells and in most forms of myelo decreased in leucopenia and pancytopenia.
Aetabolism (mmol/10^{11} leucocytes)					
)$_2$ uptake per hour.........	4.0	–	–	5	Values depend on the composition of the incubation medium.
;lucose consumption per hour	14.0	–	–	5	
.actate formation per hour ..	30.1	–	–	5	

.eucocyte count (see also the table opposite)

:easurement

Visual counting in a counting chamber or automatically using blood-cell counting apparatus. In respect of the range of error and ounting differences the remarks on pages 613–614 on erythrocyte ounting also apply. For discussion of methods and bibliography ee the literature[7].

'hysiological characteristics

Like the erythrocyte count the leucocyte count in the newborn - by one-fifth to one-quarter during the first hours of life (see iagram). As with the erythrocytes, there is a difference between the eucocyte count in the capillary and venous blood in the period ollowing birth, the count in the venous blood being 1000–1500 ower. During the first days of life there is marked neutrophilia and o a lesser extent monocytosis; the period from the 2nd week up to he 4th year is accompanied by lymphocytosis.

Slight neutrophilia occurs towards the end of pregnancy, during hysical work, emotional excitement and convulsions, and after aking adrenaline.

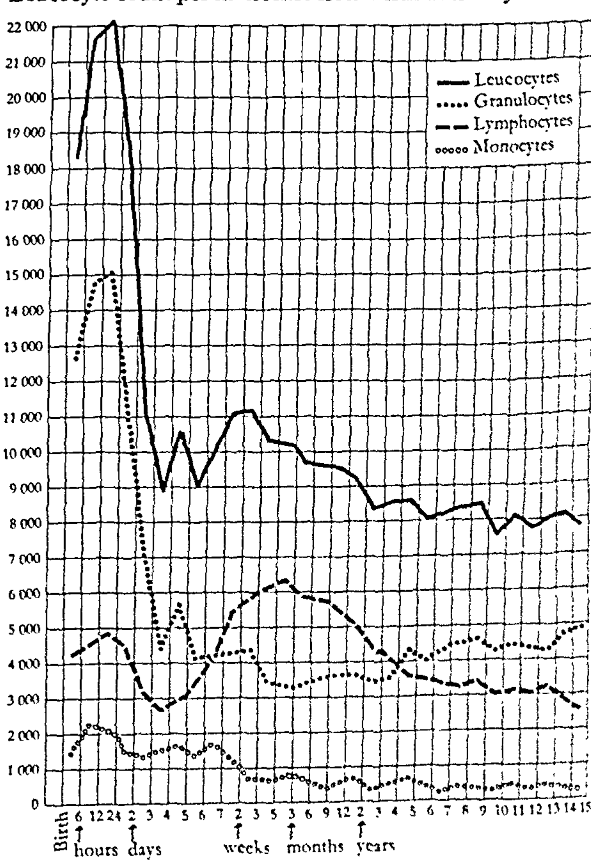
There is no sex difference in the leucocyte count[8]. Daily rhythms s well as seasonal and climatic fluctuations have been reported.

'athological characteristics

Leucocytosis usually consists of an increase in the number of eutrophils. It occurs in many infectious diseases, in all suppurative onditions due to cocci, in poisoning by various metals and drugs, n diabetic ketosis, in many cases of malignant tumours, in gastric nd duodenal ulcers, in gout and in coronary thrombosis. Excessive eucocytosis with a very marked shift to the left in the granulocytes occurs in tuberculous disease with typhoid-like symptoms. Myeloid eukaemia may be variously marked by the presence of myeloblasts, promyelocytes or monocytes, or by a mixture of these cells. Leucocytosis consisting of an increase in the lymphocytes in children is seen mainly in whooping cough and acute infectious lymphocytosis. Leucocytosis due to the presence of lymphoid monocytes is characteristic of infectious mononucleosis.

Leucopenia due to agranulocytosis or granulocytopenia occurs in salmonellosis, in typhoid (more so than in paratyphoid), very occasionally in septicaemia and miliary tuberculosis, in anaphylactic shock and in severe bone-marrow disturbances due for instance to radiation. Leucopenia consisting of lymphocytopenia or even alymphocytosis is characteristic of many antibody-deficiency syndromes[9].

Leucocyte count per microlitre from birth until 15 years[6]



Leucocytes

(For other physical and chemical data see under 'Blood', pages 557–611)

Total leucocyte count and distribution at various ages

Age		Reference	Total leucocytes Mean	Total leucocytes 95% range (extreme range in brackets)	Neutrophil granulocytes Total Mean	Neutrophil granulocytes Total 95% range (extreme range in brackets)	Stab cells Mean	Segmented cells Mean	Eosinophil granulocytes Mean	Eosinophil granulocytes 95% range (extreme range in brackets)	Basophil granulocytes Mean	Basophil granulocytes 95% range (extreme range in brackets)	Lymphocytes Mean	Lymphocytes 95% range (extreme range in brackets)	Monocytes Mean	Monocytes 95% range (extreme range in brackets)	Neutrophil myelocytes* Mean	Neutrophil myelocytes* 95% range (extreme range in brackets)
Birth	number/µl	1 2	18100	(9000–30000)	11000	(6000–26000)	1650	9400	400	(20–850)	100	(0–640)	5500	(2000–11000)	1050	(400–3100)	–	
	per cent				61		9.1	52	2.2		0.6		31		5.8			
12 hours	number/µl	1 2	22800	(13000–38000)	15500	(6000–28000)	2330	13200	450	(20–950)	100	(0–500)	5500	(2000–11000)	1200	(400–3600)	–	0–1908
	per cent				68		15.2	58	2.0		0.4		24		5.3			0–10
24 hours	number/µl	1 2	18900	(9400–34000)	11500	(5000–21000)	1750	9800	450	(50–1000)	100	(0–300)	5800	(2000–11500)	1100	(200–3100)	–	
	per cent				61		9.2	52	2.4		0.5		31		5.8			
1 week	number/µl	1 2	12200	(5000–21000)	5500	(1500–10000)	830	4700	500	(70–1100)	50	(0–250)	5000	(2000–17000)	1100	(300–2700)	–	0–437
	per cent				45		6.8	39	4.1		0.4		41		9.1			0–3
2 weeks	number/µl	1 2	11400	(5000–20000)	4500	(1000–9500)	630	3900	350	(70–1000)	50	(0–230)	5500	(2000–17000)	1000	(200–2400)	–	0–102
	per cent				40		5.5	34	3.1		0.4		48		8.8			0–1
4 weeks	number/µl	1	10800	(5000–19500)	3800	(1000–9000)	490	3300	300	(70–900)	50	(0–200)	6000	(2500–16500)	700	(150–2000)	–	–
	per cent				35		4.5	30	2.8		0.5		56		6.5			
2 months	number/µl	1	11000	(5500–18000)	3800	(1000–9000)	490	3300	300	(70–850)	50	(0–200)	6300	(3000–16000)	650	(130–1800)	–	–
	per cent				34		4.4	30	2.7		0.5		57		5.9			
4 months	number/µl	1	11500	(6000–17500)	3800	(1000–9000)	450	3300	300	(70–800)	50	(0–200)	6800	(3500–14500)	600	(100–1500)	–	–
	per cent				33		3.9	29	2.6		0.4		59		5.2			
6 months	number/µl	1	11900	(6000–17500)	3800	(1000–8500)	450	3300	300	(70–750)	50	(0–200)	7300	(4000–13500)	580	(100–1300)	–	–
	per cent				32		3.8	28	2.5		0.4		61		4.8			
8 months	number/µl	1	12200	(6000–17500)	3700	(1000–8500)	410	3300	300	(70–700)	50	(0–200)	7600	(4500–12500)	580	(80–1200)	–	–
	per cent				30		3.3	27	2.5		0.4		62		4.7			
10 months	number/µl	1	12000	(6000–17500)	3600	(1000–8500)	400	3200	300	(60–700)	50	(0–200)	7500	(4500–11500)	550	(50–1200)	–	–
	per cent				30		3.3	27	2.5		0.4		63		4.6			
12 months	number/µl	1	11400	(6000–17500)	3500	(1500–8500)	350	3200	300	(50–700)	50	(0–200)	7000	(4000–10500)	550	(50–1100)	–	–
	per cent				31		3.1	28	2.6		0.4		61		4.8			
2 years	number/µl	1	10600	(6000–17000)	3500	(1500–8500)	320	3200	280	(40–650)	50	(0–200)	6300	(3000–9500)	530	(50–1000)	–	–
	per cent				33		3.0	30	2.6		0.5		59		5.0			
4 years	number/µl	1	9100	(5500–15500)	3800	(1500–8500)	270	3500	250	(20–650)	50	(0–200)	4500	(2000–8000)	450	(0–800)	–	–
	per cent				42		3.0	39	2.8		0.6		50		5.0			
6 years	number/µl	1	8500	(5000–14500)	4300	(1500–8000)	250	4000	230	(0–650)	50	(0–200)	3500	(1500–7000)	400	(0–800)	–	–
	per cent				51		3.0	48	2.7		0.6		42		4.7			
8 years	number/µl	1	8300	(4500–13500)	4400	(1500–8000)	250	4100	200	(0–600)	50	(0–200)	3300	(1500–6800)	350	(0–800)	–	–
	per cent				53		3.0	50	2.4		0.6		39		4.2			
10 years	number/µl	1	8100	(4500–13500)	4400	(1800–8000)	240	4200	200	(0–600)	40	(0–200)	3100	(1500–6500)	350	(0–800)	–	–
	per cent				54		3.0	51	2.4		0.5		38		4.3			
12 years	number/µl	1	8000	(4500–13500)	4400	(1800–8000)	240	4200	200	(0–550)	40	(0–200)	3000	(1200–6000)	350	(0–800)	–	–
	per cent				55		3.0	52	2.5		0.5		38		4.4			
14 years	number/µl	1	7900	(4500–13000)	4400	(1800–8000)	240	4200	200	(0–500)	40	(0–200)	2900	(1200–5800)	380	(0–800)	–	–
	per cent				56		3.0	53	2.5		0.5		37		4.7			
16 years	number/µl	1	7800	(4500–13000)	4400	(1800–8000)	230	4200	200	(0–500)	40	(0–200)	2800	(1200–5200)	400	(0–800)	–	–
	per cent				57		3.0	54	2.6		0.5		35		5.1			
18 years	number/µl	1	7700	(4500–12500)	4400	(1800–7700)	230	4200	200	(0–450)	40	(0–200)	2700	(1000–5000)	400	(0–800)	–	–
	per cent				57		3.0	54	2.6		0.5		35		5.2			
20 years	number/µl	1	7500	(4500–11500)	4400	(1800–7700)	230	4200	200	(0–450)	40	(0–200)	2500	(1000–4800)	380	(0–800)	–	–
	per cent				59		3.0	56	2.7		0.5		33		5.0			
21 years	number/µl	1	7400	(4500–11000)	4400	(1800–7700)	220	4200	200	(0–450)	40	(0–200)	2500	(1000–4800)	300	(0–800)	–	–
	per cent				59		3.0	56	2.7		0.5		34		4.0			
Adults	number/µl	3	7000	2800–11200	4150	712–7588	–	–	165	0–397	44	0–112	2185	1029–3341	456	66–846	0	0
	per cent				59				2.4		0.6		31		6.5			

* These cells are also included in the stab neutrophils

[1] DITTMER, D. S. (Ed.), *Blood and Other Body Fluids*, Federation of American Societies for Experimental Biology, Washington, 1961, page 125

[2] FORKNER, C. E., *Bull Johns Hopk Hosp*, 45, 75 (1929)

[3] GRAHAM et al., *Blood*, 10, 467 (1955)

Leucocytes

(For other physical and chemical data see under 'Blood', pages 557–611)

Basophil count[10]

Physiological and pathological characteristics

1. Increased greatly in chronic myeloid leukaemia and polycythaemia, significantly in diabetes and myxoedema.
2. Decreased greatly in hyperthyroidism, after administration of glucocorticoids and during pregnancy.

Eosinophil count[11]

Physiological characteristics

1. Subject to fluctuations at intervals of a few minutes with a range exceeding the error inherent in the method of measurement.
2. Subject to marked daily periodicity with low values in the late afternoon and early morning (down to about 20% of the mean 24-hour value) and a maximum at midnight (up to about 30% of the same mean value). This periodicity is mainly seen in *fasting* subjects.
3. Subject to seasonal fluctuations (increase in the earl[y] the year and autumn).
4. Subject to change during the course of the menstr[ual] (menstrual peak, low point following ovulation).

Pathological characteristics

1. Eosinophilia occurs in parasitic infestations, in allerg[ic] tions, in functional disturbances of the spleen, and in diseas[es] blood-forming organs and central nervous system.
2. Eosinopenia arises from increased migration into the with inadequate replacement, in suppression or aplasia of poiesis due to increased corticosteroid secretion or cortic[o] administration.
3. Aneosinophilia occurs during the peak period of t fever.

Schilling's haemogram

Normal relationship of immature neutrophils (myelocytes + young neutrophils + stab neutrophils) to mature (segmented) neutrophils = 1/13 or less	Basophils	Eosinophils	Myelocytes	Neutrophils: Young cells	Neutrophils: Stab cells	Neutrophils: Segmented cells	Lymphocytes	[M…]
Normal range (%)	0.5–1.5	2–4	0	0–1	3–5	51–67	20–30	[illegible]

In order to simplify the recording of results of differential counts SCHILLING's haemogram can be written: '–,–/–,–,–,–/–,–', where the dashes represent the percentage values in the order given in the above table of the haemog[ram]. This enables the differential blood picture to be rapidly evaluated.

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[2] TIVEY et al., *Blood*, 6, 1013 (1951).
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[5] VALENTINE, W.N., *Progr. Hemat.*, 1, 293 (1956).
[6] KATO, K., *J. Pediat.*, 7, 7 (1935).
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[8] UNDRITZ and BRAGATSCH, *Schweiz. med. Wschr.*, 92, 388 (1962).
[9] GASSER, C., *Pädiatr. Fortbildungskurse (Basel)*, No. 11–12, 16 (1964).
[10] BRAUNSTEINER, H., in BRAUNSTEINER, H. (Ed.), *The Physiology and P[athology] of Leucocytes*, Grune & Stratton, New York, 1962.
[11] GROSS, R., in BRAUNSTEINER, H. (Ed.), *The Physiology and Pathology o[f Leuco]cytes*, Grune & Stratton, New York, 1962.

Thrombocytes (Platelets)

(For other physical and chemical data see under 'Blood', pages 557–579)

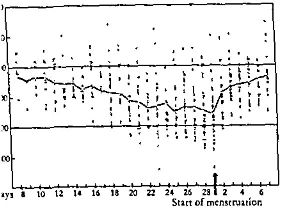
	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Thrombocyte count (in thousands per µl)					
Cord blood	227	149–305	39	1	Determined by the direct method. There are no marked differences as sex or age are concerned[3]. The thrombocyte count is rather low prior t[o] at the start of menstruation and rises after cessation of menstruation[4] [Dif]ferences in the count due to constitution, physical exercise, altitude an[d am]bient temperature have been reported. The thrombocyte count is *increase[d]* injury and in chronic myeloid leukaemia, *decreased* in thrombopenic pur[pura]
Children					
1 week (cutaneous blood)	233	143–323	45	1	
1 month (cutaneous blood)	277	175–379	51	1	
3 months (cutaneous blood)	348	220–476	64	1	
12 months (cutaneous blood)	339	219–459	60	1	
Adults					
cutaneous blood	250	133–367	58.5	2	
venous blood	310	286–334	11.9	2	
arterial blood	350	322–378	13.9	2	
Thrombocytocrit value (thrombocyte packing volume) (ml/l)	4.8	(3.3–8.3)	–	5	Proportion of the peripheral venous blood volume occupied by the thro[mbo]cytes.
Diameter (µm)	–	(2–4)	–	2, 6	Normally the thrombocytes are spherical or egg-shaped. They undergo ch[ange] of shape even after brief contact with a wettable surface[5,7].
Volume (fl ≡ µm³)	–	(10–12)	–	2	Dependent on temperature and on concentration of anticoagulants[8]. *Incr[eased]* in thrombopenic purpura and a few other diseases[5].
	16.2	(10.3–19.7)	–	5	
	5.8	–	–	8	
Lifetime (days)	–	(8–14)	–	9	Measured by the ³²P-di-isopropyl fluorophosphate (DFP) method. Red[uced] in polycythaemia vera accompanied by thrombopenia[10].
Half-life (days)	–	(5–6)	–	11	Measured by means of ¹⁴C-serotonin.
Osmotic resistance	...	...	...	...	Morphological changes in the thrombocytes occur with NaCl concentrati[ons] of 0.44% and below; at a concentration of 0.1% almost all the thromboc[ytes] are in the form of ghosts[12]. The osmotic resistance is lowered in idiop[athic] thrombocytopenia[12], increased in thrombopathic conditions[12] and altered in some infectious diseases[13].

Thrombocytes (Platelets)

(For other physical and chemical data see under 'Blood', pages 557–579)

	Mean	95% range	*s*	Refer-ence	Remarks
lsm (μmol per 10[11] thrombocytes)					
:e per hour	86 3	73 5–99.1	6.4	14	Values depend on the composition of the incubation medium
nation per hour . .	95.7	74 9–117	10 4	14	
: formation per hour	3.9	3 1–4.7	0.4	14	
formation per hour .	76 4	52 6–100	11.9	14	

bocyte count during menstruation[15]



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[15] Pohle, F J , *Amer J med Sci* , 197, 40 (1939)

Bone marrow

›where in haematology are such conflicting data to be found as ıg the percentages of the various types of cell present in human : marrow This is a result of differences in counting techniques greater the amount of marrow aspirated, the greater the volume ood entering the syringe The proportions of erythroblasts and granuloblasts fall while those of the stab and segmented cell lymphocytes rise The last three types of cell are really constit of the marrow blood and their numbers can therefore be enr at any time from the peripheral blood On values in adults se ticularly the monograph by Rohr[1].

:logram at various ages[2]

Type of cell	24 hours Range (%)	24 hours Mean (%)	End of new-born period Range (%)	End of new-born period Mean (%)	Infancy Range (%)	Infancy Mean (%)	Early childhood Range (%)	Early childhood Mean (%)	School age Range (%)	School age Mean (%)	Adults Range (%)
:rythroblasts											
basophil	0 5–10 0	5 0	0 0– 3 0	1.0	0 5– 5 0	2 5	1 0– 6 0	2 5	1 0– 8 0	3 0	0 5– 7 5
polychromatic	7 5–30 0	15.0	0 0–10 0	3 0	5 0–20 0	10 0	3 0–10 0	5 0	3 0–10 0	6 0	2 0–15 0
oxyphil	7 5–30 0	15.0	2 0–20 0	6 0	5 0–12 5	7 5	5 0–20 0	10 0	5 0–20 0	11 0	5 0–25.0
Total		35.0		10 0		20 0	.	17.5	.	20 0	.
:ranulopoiesis											
Myeloblasts	0 2– 5 0	2.5	0 2– 5 0	2 0	0 2– 5 0	1 5	0 2– 5 0	1 0	0 2– 5 0	1 0	0 5– 5.0
Promyelocytes	0 2– 5 0	3 0	0 5– 7 5	3 5	0 5–10 0	2 5	0 5– 7.5	2 5	0 5–10 0	3.0	0 – 7 5
Myelocytes	2 0–20 0	6 0	5 0–20 0	10 0	5 0–15 0	10 0	5.0–20 0	12 5	5 0–25 0	15 0	5 0–25.0
Metamyelocytes	5 0–25 0	12 5	5 0–25 0	12 5	5 0–15 0	10 0	5.0–20 0	12 5	5 0–25 0	15 0	5.0–20 0
Stab cells	5 0–25 0	12 5	10 0–25 0	15 0	5 0–15 0	8 0	5 0–15 0	10 0	5 0–20 0	12 5	5 0–25 0
Segmented cells	10 0–30 0	15 0	10 0–25 0	15 0	1 0–15 0	7 0	1.0–15 0	8 5	1 0–15 0	8 0	0 5–15 0
Eosinophils	0 0– 5 0	1.0	0 5– 7 5	2 5	1 0– 7 5	4 0	1 5– 7.5	5 0	1 0– 7 0	4 0	1 5– 7 5
Basophils	0 0– 0.5	0.05	0 0– 1 0	0 05	0 – 1 0	<0 05	0 – 0 5	<0 1	0 – 1 0	<0 2	0 – 1.0
Total		52 5		60 0		43 0		52 0	.	58 5	...
Monocytes*	3 0–15 0	7.5	2.0–10 0	5 0	0 5– 5 0	2 0	1 0– 5 0	3 0	0 5– 4 0	1 5	0 5– 3.0
Lymphocytes**					.		.	.	.	. .	2 5–15 0
Reticular cells**	0 0–10 0	5 0	10 0–40 0	25 0	15 0–50 0	35 0	15 0–40 0	27 5	10 0–35 0	20.0	1.5–20 0
Plasmacytes	0 0– 1 0	0.1	0 0– 1 5	0 1	0 – 2 0	<0 5	0 – 2 5	<0 5	0 2– 2 5	0.5	0 5– 3 0
Megakaryocytes		0 1		0 1		<0 5	. .	<0 5	.	<0 5	...

* The high value for monocytes in the marrow of the newborn is probably synchronous with the peripheral monocytosis of the first weeks of life

** Here no distinction is made between lymphoid reticulum and lym cytes since the data in the literature show large discrepancies

References
[1] R(
[2] Opitz and Watson in [illegible]

Blood Coagulation*

(For references see page 625)

Physiology

The processes involved in the coagulation of blood are still to some extent obscure, so that the diagrammatic representation shown here (Fig. 1) should not be regarded as conclusive.

Normally, the blood begins to coagulate when it escapes as a result of injury to a vessel and comes into contact with a foreign, wettable surface, for instance damaged tissue. In the presence of calcium ions, contact of the blood with such a surface results in the activation of Factor XII, which in turn initiates the viscous metamorphosis of the thrombocytes in a manner as yet unknown. The thrombocytes become labile, and as a consequence agglutinate to the foreign surface, to one another and to other cells. The result is the formation of a platelet thrombus and the release of a number [illegible] causes the activation in succession of Factors XI, IX, VIII and X in a chain reaction. The activated Factor X, together with the lipoid factor of the thrombocytes, forms active plasma thromboplastin (the so-called intrinsic system).

Factor X is likewise activated in the presence of calcium ions by the tissue fluid in conjunction with Factor VII. The Factor X activated by this system (the so-called extrinsic system) brings about the formation of active tissue thromboplastin. The formation of both these active thromboplastins is accelerated by Factor V.

In the first phase of coagulation the two active thromboplastins – plasma thromboplastin and tissue thromboplastin – act on the prothrombin and convert it into thrombin.

Heparin inhibits the activity of both the thromboplastins and thrombin. At this stage other antithrombins likewise function as antagonists in the coagulation process.

In the second stage of coagulation thrombin acts on the fibrinogen, which is thereby converted into monomeric, soluble fibrin. The latter now polymerizes and is converted under the action of Factor XIII and calcium ions into stable fibrin.

In the third phase the fibrin clot undergoes retraction under the action of the agglutinated thrombocytes.

The retracted clot may eventually be broken down by plasmin to yield soluble products. Plasmin is a rather nonspecific proteolytic enzyme; under pathological conditions it is also capable of breaking down fibrinogen and other protein components of the coagulation system. Plasmin is formed from plasminogen as a result of a complicated series of activation processes, commencing with the formation of an activator by the action of lysokinases – present in both blood and tissues – on a proactivator of the blood. This activator converts plasminogen into plasmin. The latter can also arise from plasminogen directly via a tissue activator. Lysokinases are inhibited by antilysokinases, plasmin activity by antiplasmin.

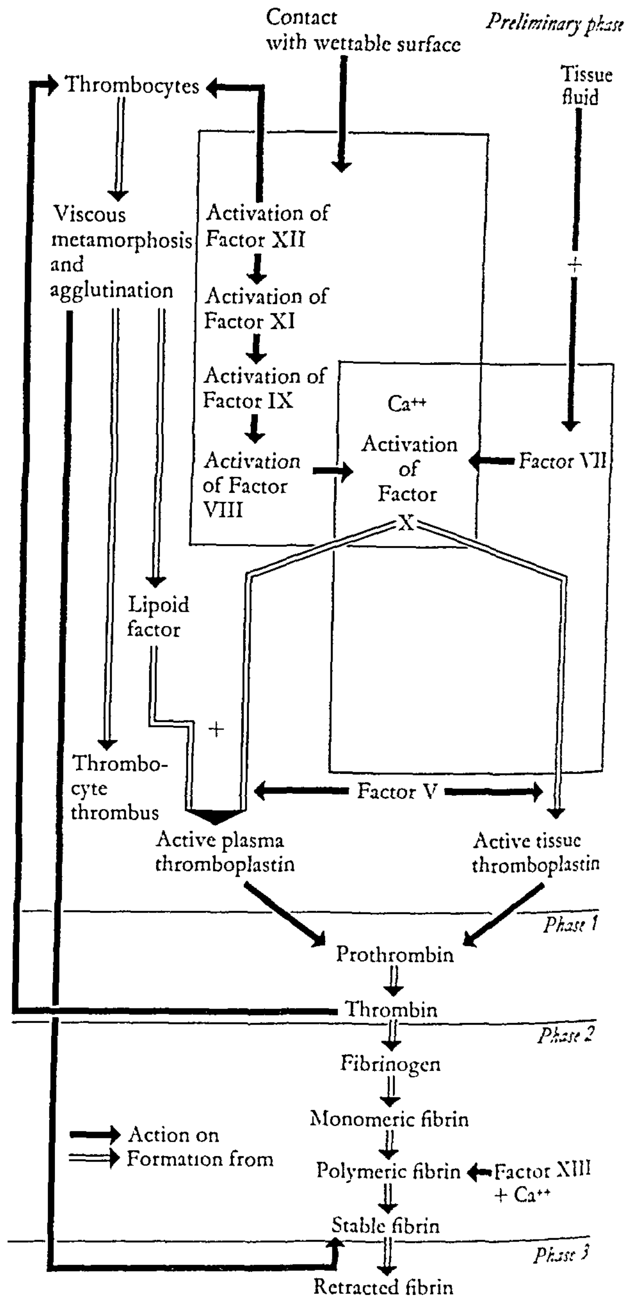

Fig. 1

Physiological variations

The coagulation process does not function fully in all newborn children. On the average, the concentrations of fibrinogen and Factors II, VII, IX and X are low, especially during the first few days of life; there are considerable individual variations, however, and values above normal may even be encountered[1].

The number and functional state of the thrombocytes are both within the normal range in newborn infants, both full-term and premature (see also page 620).

Ageing as such does not appear to involve any alteration in the coagulation process. Pathological changes are probably in most cases due to changes in either the coagulation process or the vessels. Impairment of the coagulation system due to certain foodstuffs appears to be commoner in old age; an example is the increased tendency to coagulation after a meal rich in fats[2].

During pregnancy the concentrations of Factors VII and X in the blood are often increased. The occasional rise in the blood levels of Factor IX and fibrinogen, combined with an enhanced tendency of the thrombocytes to agglutinate in the presence of an increased blood phospholipid concentration, may lead to thrombo-embolic complications during pregnancy[3].

Pathology

The pathology of blood coagulation comprises three main types of disease: thrombosis with the concomitant danger of embolism, the haemorrhagic diatheses, and cardiac infarction.

Thrombo-embolism

In the vessels, plasmatic coagulation of the blood can come about through exhaustion of the endogenous heparin or, in general, through a reduction in the antithrombin level.

Lowering of platelet stability through activation of Factors XII and X (for instance as a result of pathological changes in the vascular wall) or following some specific thrombocytic disease can likewise enhance the tendency to coagulation. The same result can come about through inhibition of the fibrinolytic system by physiological inhibitors, drugs or disease. Stasis due to a diminished rate of blood flow also favours thrombosis.

The sites where thromboses are most likely to occur are shown in order of frequency in Figure 2.

Theoretically feasible methods of treatment are first a reduction in the plasmatic coagulation potential by means of oral anticoagulants, secondly inhibition of the activity of the thromboplastins and thrombin by means of heparin, thirdly stabilization of the thrombocytes, i.e., inhibition of the contact activation process (inhibition of the activity of Factor XII), and lastly an increase in fibrinolytic activity.

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* This chapter (pages 622–625) has been compiled by C. Montigel, Research Laboratories of J. R. Geigy S.A., Basle (Switzerland).

(For references see page 625)

·hagic diatheses

.creased tendency to bleeding may be due to an abnormal in fibrinolytic activity (caused by physiological activators, or drugs), to enhanced stability of the thrombocytes, to ›cytopenia or hereditary thrombo-asthenia, and finally to on of the plasmatic coagulation process as a result of an : in endogenous heparin, a rise in the antithrombin titre, a cy of certain factors, or drug action

matic coagulation system by an excess of endogenous heparin or heparin-like inhibitors can be overcome by administering prota-

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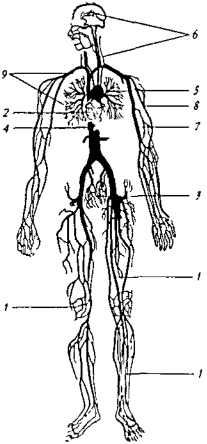

Cardiac infarction

In spite of certain common external causes and initiating mechanisms, the pathogenesis of cardiac infarction differs considerably from that of thrombosis[4] Only in rare cases are primary coagulation thrombi found in cardiac infarction Many aspects of the disease are still unexplained

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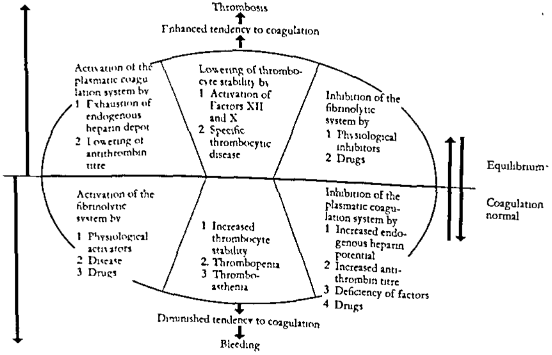
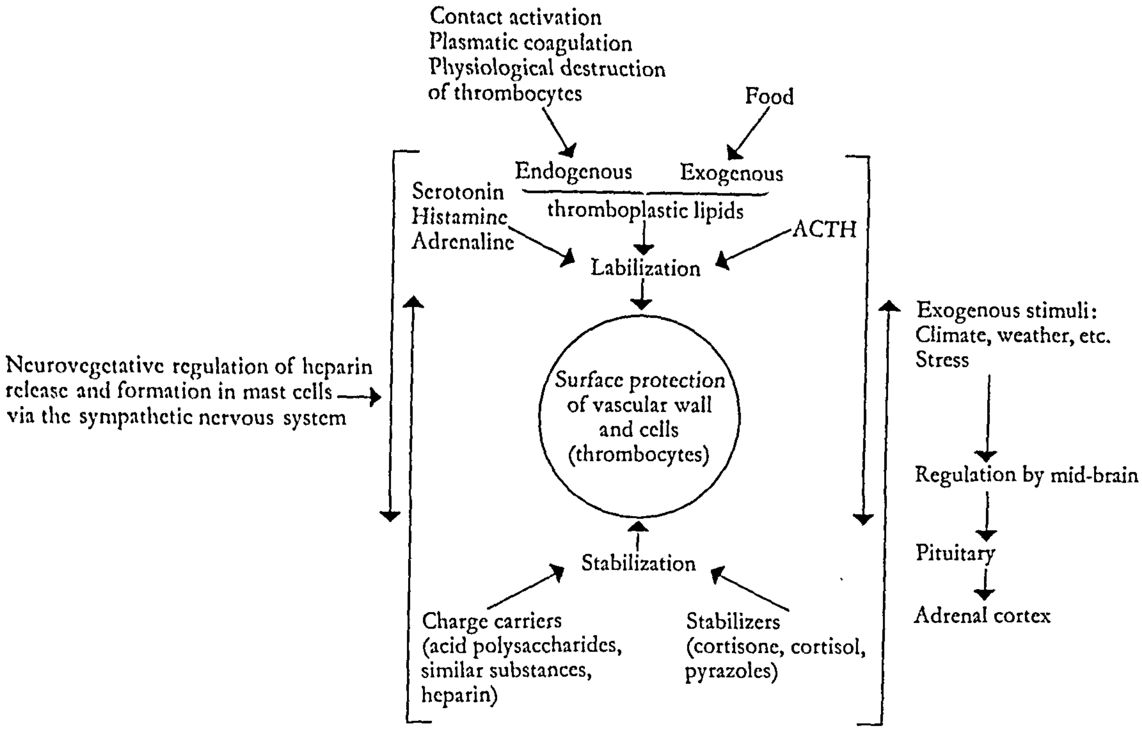




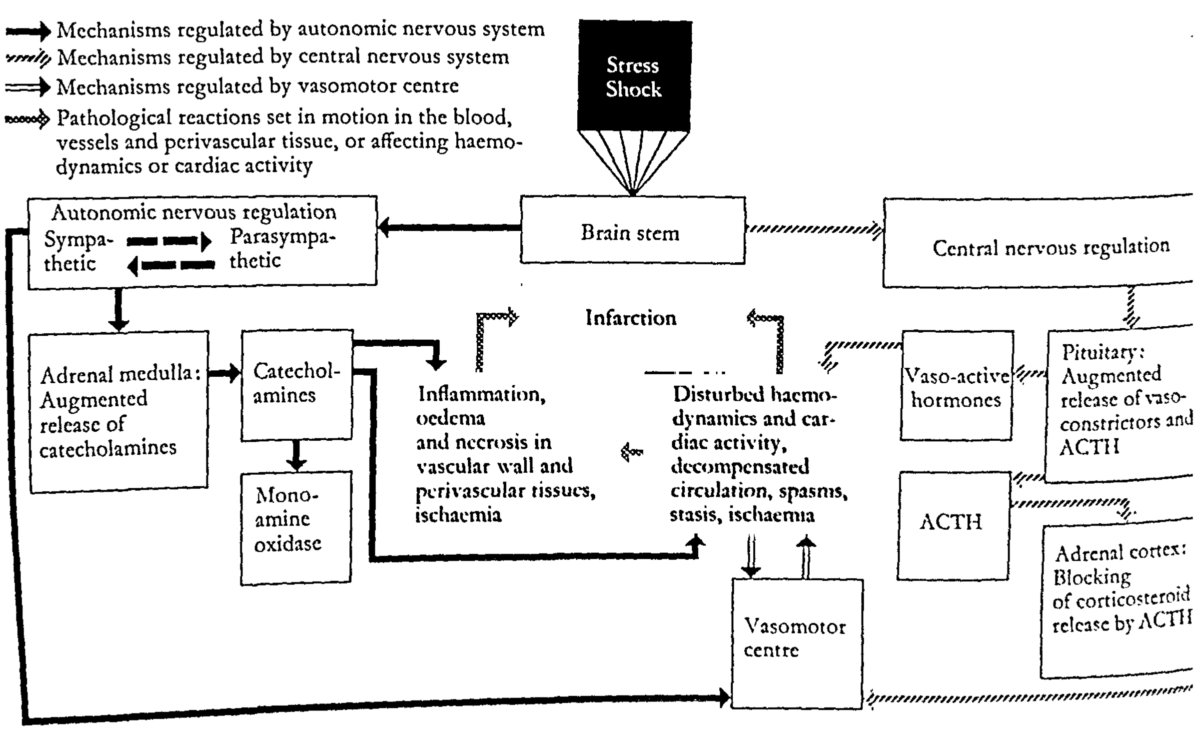
results in the formation of necrotic areas in the vascular walls and in the heart, particularly beneath the endocardium, in the wall of the left ventricle, in the septum and in the apex, in fact in any part where a high concentration of monoamine oxidase can be demonstrated histologically[5]. This necrosis causes a manifest infarct either directly or via the development of oedema in the coronary vessels. The action of catecholamines in causing necrosis, oedema and thus infarction is also favoured by the hypertension, spasms, stasis and ischaemia that commonly result from a disturbance of haemodynamics and cardiac activity.

The process of infarction initiated in this way is intensified by mechanisms under central nervous control and mediated by the pituitary and vasomotor centre[6]. The pituitary releases larger amounts of vasoconstrictor substances, with the result that the haemodynamic equilibrium is disturbed. At the same ti regulation of cardiac activity and of haemodynamics by th motor centre is impaired. The increased release of ACTH pituitary blocks the release of corticosteroids by the adrenal so that the stability of the vascular wall is endangered (Fig.

Methods

The coagulation process can be studied by various *routine* suitable for any laboratory:

Bleeding time. Measured by making a small wound in a cap small vein or arteriole. The results depend on the condition plasmatic, thrombocytic and fibrinolytic coagulation systems. I entiation is not possible.



Recalcification time. This method is particularly useful for meas-ing the effect of heparin and heparinoids on the plasmatic coag-ation system.

st since it is modified in certain thrombocytic diseases as well as uring treatment with heparin

Heparin tolerance test. By measuring the coagulability of the blood his test makes it possible to assess the patient's tendency to throm-osis

A number of *special methods*, suitable only for appropriately quipped laboratories, are available for determining individual actors and functions involved in the physiological coagulation process. They require the use of either expensive apparatus like the hrombo-elastograph and thrombocyte aggregometer or special reagents which must be prepared in the laboratory itself. Tho special methods whose reliability is now established are listed in t table below. For a detailed description of the techniques involv see MONTIGEL[7].

References

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Special methods of studying blood coagulation

Phase of coagulation	Factor or phase tested	Method	Reagent	Remarks
Preliminary phase, intrinsic system, thrombocytic process	Thrombocyte function	Thrombo-elastograph Thrombocyte aggregometer (BREDDIN's method)		
Preliminary phase, intrinsic system, plasmatic process	Contact activation Factor XII	Thrombo-elastograph Thrombocyte aggregometer		
Preliminary phase, intrinsic system, plasmatic process	Factor X	Measurement of coagulation	Factor X-free plasma + viper toxin + phospholipids	
extrinsic system, plasmatic process			Factor X-free plasma + tissue thromboplastin	Only when Factor VII is present in adequate amount
Preliminary phase, extrinsic system	Factor VII	Measurement of coagulation	Factor VII-free plasma + tissue thromboplastin	
Preliminary phase, plasmatic process	Factor V	Measurement of coagulation	Factor V-free plasma + tissue thromboplastin	
Preliminary phase, plasmatic process, inhibitors	Antithrombin II	Measurement of coagulation after addition of fibrinogen	Fibrinogen solution	
Phase 1	Factor II Prothrombin	Measurement of coagulation	Factor II-free plasma + tissue thromboplastin	
Phase 2	Factor I			No satisfactory routine method
Phase 3	Retraction potential of thrombocytes	Measurement of clot retraction		
Phase 4	Fibrinolytic potential	Plasmolysis time		

Blood Groups*

(For references see pages 633–634)

The blood groups[1] consist of inherited characters of the blood corpuscles, particularly the erythrocytes, identifiable as antigens by means of their reaction with specific antibodies. The genes responsible for the presence of these antigens are inherited in accordance with Mendelian principles. Most of the blood-group characters are already identifiable in the young embryo and remain unchanged throughout life. They are unaffected by external factors like climate or, in general, disease[2].

The blood-group characters can be arranged into systems, those so far recognized being the AB0, MNSs, P, Rh, Lutheran, Kell, Lewis, Duffy, Kidd, Diego, Ii, Auberger, Xg, Yt and Dombrock systems. With one exception, each of these systems is inherited independently of the others as an autosomal character; the exception is the Xg group, which is located on the X chromosome. Also known are blood-group antigens of very rare occurrence ('private antigens'), like the Levay, Jobbins, Becker, Ven, Rm, Chr^a, Wr^a, Be^a, By, Sw^a, Good, Bi and Tr^a antigens, as well as others only rarely absent from human erythrocytes, like Vel, Ge, Lan and Sm ('public antigens').

An individual's blood-group characters are identifiable by means [illegible] [illegible]odies. These may be of human origin [illegible] either agglutinins or incomplete antibodies. The antibodies are either naturally occurring, i.e., they have not arisen from any known immunizing stimulus, or they are immune antibodies due to an immunizing stimulus such as pregnancy or blood transfusion or injection. Test sera containing hetero-antibodies may also be produced by immunizing suitable animals. Finally, certain reagents of vegetable origin (phytagglutinins) can be used to identify particular blood-group characters (A_1, A_2, H, M, N, etc.).

An antigen-antibody reaction takes place between the test serum and the antigen-carrying erythrocytes leading either to agglutination or, occasionally, in the presence of complement, to haemolysis.

At the right temperature, the agglutinins react with erythrocytes suspended in physiological salt solution. Reaction with incomplete antibodies may be demonstrated

(a) in viscous reaction media, 22–30% beef albumin being a particularly suitable one; other substances used for this purpose include human serum or plasma free of antibodies, gelatin, dextran, polyvinylpyrrolidone, gum arabic, etc.

(b) in the fermentation test; in the main the following proteolytic enzymes are used: trypsin, papain, bromelain and ficin.

(c) in the indirect antiglobulin test (Coombs' test).

Combinations of tests (for instance a trypsin test combined with an indirect antiglobulin test) are particularly sensitive.

The AB0 blood-group system (Landsteiner, 1900[3])

The iso-antibodies anti-A and anti-B are normal and regular constituents of appropriate human blood sera. Two antigens (agglutinogens) A and B, reacting respectively with anti-A and anti-B, enable an individual's blood to be assigned to one of the four groups A, B, AB or 0.

Table 1

Reaction with anti-A ...	+	–	+	–
Reaction with anti-B	–	+	+	–
Blood group	A	B	AB	0

The antigen is located on the surface of the erythrocytes, while the serum contains the iso-antibody, either anti-A or anti-B, corresponding to the antigen not carried by the erythrocytes; if both antigens are carried, or both lacking, the serum contains respectively neither iso-antibody, or both:

Table 2

Blood group	Antigen carried by erythrocytes	Antibodies in serum
0	–	anti-A + anti-B
A............	A	anti-B
B	B	anti-A
AB	A and B	neither

* The chapters on 'Blood Groups' and 'Serum Groups' (pages 626–634) have been compiled by L. P. Holländer, Blood Donor Centre of the Swiss Red Cross, Basle.

From the genetic aspect, an allelic gene (*A*, *B* or *0*) i[s] a chromosomal locus, the blood group being determi[ned by the] combined effect of the two genes situated at the equi[valent loci.] Phenotypically, the character 0 is found only in the h[omozygous] form.

The four blood groups (phenotypes) arise from the [six] genotypes, as shown in Table 3. It is impossible to distin[guish sero]logically between *AA* and *A0* or between *BB* and *B0*.

Table 3

Blood group (phenotype)	Genotype
0	*00*
A	*AA* or *A0*
B	*BB* or *B0*
AB	*AB*

The frequencies with which the various blood gro[ups occur] within a population differ widely. From these phenotyp[e frequen]cies the corresponding gene frequencies can be calcu[lated (for] formulae see Race and Sanger[1]). Such data are of great in[terest] in anthropological studies.

Subgroups of the AB0 system

The blood group A can be subdivided into A_1 and [A_2 (von] Dungern and Hirszfeld[4]), the blood group AB into [A_1B and] A_2B. Anti-A sera (from B individuals) consist of two com[ponents,] anti-A and anti-A_1. Anti-A_1 reacts only with erythrocytes [of groups] A_1 and A_1B, anti-A on the other hand with groups A_1, A_2, [A_1B and] A_2B. This subdivision of A increases the number of poss[ible] blood groups from four to six, namely 0, A_1, A_2, B, A_1B [and A_2B.] There are 10 genotypes corresponding to these phenotypes (

Table 4

Blood group (phenotype)	Genotype
0	*00*
A_1	A_1A_1, A_1A_2, A_10
A_2	A_2A_2, A_20
B	*BB*, *B0*
A_1B	A_1B
A_2B	A_2B

Anti-A_1 is present as an irregular antibody in the serum c[...] of A_2 individuals and about 26% of A_2B individuals.

Table 5 summarizes the serological data of the A_1A_2B0 [...]

Table 5

Blood group	Reaction with test serum: anti-A	anti-A_1	anti-B	Antibodies regularly present in serum	Antibo[dies] occasio[nally] present in
0	–	–	–	anti-A (+ anti-A_1) anti-B	–
A_1.....	+	+	–	anti-B	–
A_2.....	+	–	–	anti-B	anti-A_1 in about 1
B......	–	–	+	anti-A (+ anti-A_1)	–
A_1B ...	+	+	+	none	–
A_2B ...	+	–	+	none	anti-A_1 in about 2

The A subgroups can also be determined by means of phyt[agglu]tinins. *Dolichos biflorus* extract reacts specifically with A_1, a[n] extract of *Lotus tetragonolobus* seeds can be used as anti-A_2 re[...]

ry rare cases a blood cannot be assigned to one of the A subgroups, when it is assumed to belong to an intermediary subgroup (A_{int}).

le 6

Test serum	A_1	A_2	A_3	A_x	A_m
eaction with test sera anti-A (blood group B)	+	+	+*	−(+)	−(+)
anti-A+B (*blood group 0*) ...	+	+	+*	+	−(+)
anti-A_1 ...	+	−	−	−	−
eaction of serum with rythrocytes A_1	−	(+)	−	+	−
A_2	−	−	−	−	−
B	+	+	+	+	+
A' substance present in saliva of secretors	Yes	Yes	Yes	No	Yes

* Mixed agglutination

In the very rare ...

... A and B antigens have also been identified on thrombocytes and leucocytes. The chemical constitution of the A, B and H group substances has been largely elucidated.

The MNSs blood-group system (Landsteiner and Levine, 1927[10])

The M and N antigens of human erythrocytes can be identified by means of heterospecific *immune sera* from rabbits. Phenotypes and genotypes of the M and N properties are shown in Table 7.

Table 7

Reaction with anti-M	+	+	−
Reaction with anti-N	−	+	+
Phenotype (*blood group*)	M	MN	N
Genotype	*MM*	*MN*	*NN*

enables nine genotypes to be distinguished (Table 8). The genotypes *MS/Ns* and *Ms/NS* cannot be distinguished serologically.

Table 8

	MS/MS	*MS/Ms*	*Ms/Ms*	*MS/NS*	*Ms/Ns*	*MS/Ns or Ms/NS*	*NS/NS*	*NS/Ns*	*Ns/Ns*
anti-M ..	+	+	+	+	+	+	−	−	−
anti-N ..	−	−	−	+	+	+	+	+	+
anti-S ...	+	+	−	+	−	+	+	+	−
anti-s ...	−	+	+	−	+	+	−	+	+

Weak forms of M or N (M_2, N_2) are occasionally met with. They are characterized by reacting only weakly with anti-M or anti-N sera. M^c (Dunsford et al.[13]) reacts with most anti-M and some anti-N sera and is considered to be intermediate between M and N. The M_1 antigen (Jack et al.[14]) is qualitatively different from M and is

samples except those that were negative to anti-S and anti-s. This so-called anti-U behaves like an inseparable mixture of anti-S and anti-s. Individuals who form anti-U possess neither S nor s. The

an allele of M or N, S or s, though also forming part of the MNSs complex. Further antigens belonging to this system are Ri^a and St^a (Cleghorn[24]), Mt^a[25], Cl^a[26] and Ny^a[27].

The P blood-group system (Landsteiner and Levine, 1927[28])

Human bloods react either positively or negatively with anti-P sera. In the serum of P ...

Table 9

		Phenotype	Genotype
anti-P	+	P+	*PP* or *Pp*
	−	P−	*pp*

(For references see pages 633–634)

Table 10

Reaction with anti-P_1 (anti-P)	+	–	–
Reaction with anti-P + P_1 (anti-Tj^a)	+	+	–
Genotype	$P_1P_1(PP)$ $P_1P_2(Pp)$ $P_1p(PTj^b)$	$P_2P_2(pp)$ $P_2p(pTj^b)$	$pp(Tj^bTj^b)$
Phenotype	P_1	P_2	p

The designation in brackets is that usual prior to 1955.

The Rhesus blood-group system (Landsteiner and Wiener, 1940[32])

The discovery of the Rh blood-group system proved to be of great practical importance in view of the fact that Rh-negative persons form *Rh* antibodies fairly frequently after contact with the Rh antigen (transfusion or injection of blood, pregnancy). A second transfusion with Rh-positive blood may result in a haemolytic transfusion reaction. In women the result may be haemolytic disease in her newborn children (Levine et al., 1941[119]). For clinical purposes the distinction between Rh-positive and Rh-negative is usually sufficient, but in fact the Rh blood-group system is extremely complex. This complexity is one of the reasons why various genetic explanations of the Rh groups have been put forward and at least three different nomenclatures are in use. Wiener's concept[33] assumes the existence of a single gene locus on the chromosome with multiple alleles. Each allele results in the formation of an agglutinogen possessing several factors. These factors act as antigens and can be detected by means of the corresponding antibodies. On the other hand, according to Fisher and to Race[34] the Rh group to which a blood belongs is determined by three closely linked gene pairs. Each individual inherits three Rh genes from his parents, namely *C* or *c*, *D* or *d* and *E* or *e*, in the form of an indivisible gene complex. For instance, an individual inherits *CDe* from one parent and *cde* from the other. Table 11 (from Race and Sanger[7]) illustrates the two concepts using CDe as an example.

Table 11

	Gene	Agglutinogen	Factors	Antibodies
Wiener	R^1	Rh_1	Rh_0	anti-Rh_0
			rh′	anti-rh′
			hr″	anti-hr″
Fisher and Race	*C*	C		anti-C
	D	D		anti-D
	e	e		anti-e

The correspondence between Wiener's factors and the antigens of Fisher and Race, together with that between the respective antibodies, is shown in Table 12.

Table 12

Rh_0 = D	anti-Rh_0 = anti-D
rh′ = C	anti-rh′ = anti-C
rh″ = E	anti-rh″ = anti-E
hr′ = c	anti-hr′ = anti-c
hr″ = e	anti-hr″ = anti-e

Antigens have since been discovered which correspond partially to further alleles on the same single gene locus.

Alleles and variants of D

Stratton[35] has described the antigen D^u, which reacts positively with some anti-D sera, negatively with others. D^u occurs in various strengths (high-grade and low-grade) and appears to be identical with Wiener's intermediate form ($\mathfrak{Rh}_0$). In D^u individuals the antigen D can cause the formation of anti-D. The fact that D-positive individuals can also form anti-D (Argall et al.[36]) led Wiener and Unger[37] to assume the existence of partial antigens of D. Individuals not possessing one of these partial factors can form antibodies against it. $\mathfrak{Rh}^a$ indicates a blood in which the partial factor Rh^A is missing and which reacts with anti-Rh_0 and also with anti-Rh^B, anti-Rh^C and anti-Rh^D. These variants and their reactions are shown in Table 13.

Table 13

Variant	Reaction with anti-Rh_0	anti-Rh^A	anti-Rh^B	anti-Rh^C	anti-Rh^D
$\mathfrak{Rh}^a$	+	–	+	+	+
$\mathfrak{Rh}^b$	+	+	–	+	+
$\mathfrak{Rh}^c$	+	+	+	–	+
$\mathfrak{Rh}^d$	+	+	+	+	–
$\mathfrak{Rh}^{ab}$	+	–	–	+	+
$\mathfrak{Rh}^{abc}$	+	–	–	–	+
$\mathfrak{Rh}^{ac}$	+	–	+	–	+

The antigen described by Chown et al.[38] as reacting with the antibody anti-Wiel appears to be a further partial antigen of D^u.

Alleles and variants of C and c

C^W (Callender and Race[39]) is a third allele and reacts with a specific anti-C^W serum. Most anti-C sera also possess an anti-C^W component. A rare and weakly reacting antigen is C^u (Race et al.[40]), a parallel to D^u. Anti-C^x is a not very rare antibody reacting with the very rare antigen C^x (Stratton and Renton[41]).

Alleles and variants of E and e

The antigen E^u (Ceppellini et al.[42]) is analogous to D^u and C^u. E^W (Greenwalt and Sanger[43]) has so far been found only in a very few families, e^s (Sanger et al.[44]) only in members of the negro race. Shapiro[45] found the antibody anti-hr^s in the serum of a Bantu woman; the factor hr^s occurs not only among the Bantu but also in white races. The antigen e^i was found among the Columbian Indians (Layrisse et al.[46]).

Table 14 shows Wiener's analysis of the Rh phenotypes occurring in the white population of New York City[47], Table 15 their distribution among the English people as determined by Race et al.[48].

During the last few years compound antigens of the Rh system have been discovered, for instance ce, which reacts with the antiserum originally designated anti-f (Rosenfield et al.[49]). Other compound antigens are rh_i or Ce (Rosenfield and Haber[50]), CE (Tippett et al.[51]) and ce^s, which reacts with the serum originally designated anti-V (DeNatale et al.[52]). The antigen G described by Allen and Tippett[53] is not a compound antigen in the same sense; it is closely related to C and D, since most C- or D-positive individuals are also G-positive. Anti-G is found in the serum of cde and cdE individuals, most of whom also form the antibody anti-D + C.

The first case of a 'deficient' Rh chromosome was described by Race et al.[54] and designated by them –D– ($\bar{R}h_0$ in Wiener's nomenclature). Others have since come to light, namely C^wD– (Gunson and Donohue[55]), cD– (Tate et al.[56]), – – – (Vos et al.[57]). It is not known whether these are cases of gene suppression or gene depression.

The antigen contents of the individual gene complexes are summarized in Table 16 (page 631) (from Race and Sanger[7]).

An Rh complex with gene depression has been given the designation r^G (Allen and Tippett[53]). Similar behaviour is shown by the antigens of the complexes r^M (Tippett et al.[51]) and r^L (Metaxas and Metaxas-Bühler[58]).

In 1962, Rosenfield et al.[59] proposed a new terminology for the Rh groups in which the Rh antibodies were given numbers in the *chronological order of their identification*. The original publication listed 21 antibodies, since when the number has risen to 27 (Keith et al.[60]). This nomenclature is without prejudice to any

Table 14 Rh–Hr phenomena and genotypes (from

2 Rh phenotypes			12 Rh phenotypes					28 Rh–Hr phenotypes					55 genotypes
Designation	Approximate frequency among New York City whites %	Reaction with anti Rh_0 or anti rhesus	Type	Approximate frequency among New York City whites %	Reaction with anti-rh′	anti-rh″	anti rh^w	Designation	Approximate frequency among New York City whites %	Reaction with anti hr′	anti hr″	anti-hr	
Rh-negative	15	−	rh	14.4	−	−	−	rh	14.4	+	+	+	rr
			rh′	0.46	+	−	−	rh′rh	0.46	+	+	+	$r'r$
								rh′rh′	0.0036	−	+	−	$r'r'$
			rh'^w	0.004	+	−	+	$rh'^w rh$	0.004	+	+	+	$r'^w r$
								$rh'^w rh'$	0.00006	−	+	−	$r'^w r'$ or $r'^w r'^w$
			rh″	0.38	−	+	−	rh″rh	0.38	+	+	+	$r''r$
								rh″rh″	0.0025	+	−	−	$r''r''$
			rh_y	0.01	+	+	−	rh′rh″	0.006	+	+	−	$r'r''$
								$rh_y rh$	0.008	+	+	+	$r^y r$
								$rh_y rh'$	0.0001	−	+	−	$r^y r'$
								$rh_y rh''$	0.0001	+	−	−	$r^y r''$
								$rh_y rh_y$	0.000001	−	−	−	$r^y r^y$
			rh_y^w	0.00005	+	+	+	$rh'^w rh''$	0.00005	+	+	−	$r'^w r''$
								$rh_y^w rh'$	0.000001	−	+	−	$r'^w r^y$
Rh-positive	85	+	Rh_0	2.1	−	−	−	Rh_0	2.1	+	+	+	R^0R^0 or R^0r
			Rh_1	50.7	+	−	−	Rh_1rh	33.4	+	+	+	R^1r, R^1R^0 or R^0r'
								Rh_1Rh_1	17.3	−	+	−	R^1R^1 or R^1r'
			Rh_1^w	3.3	+	−	+	$Rh_1^w rh$	1.6	+	+	+	$R^{1w}r$, $R^{1w}R^0$ or $R^0r'^w$
								$Rh_1^w Rh_1$	1.7	−	+	−	$R^{1w}R^1$, $R^1r'^w$, $R^{1w}r'$, $R^{1w}R^{1w}$ or $R^{1w}r'^w$
			Rh_2	14.6	−	+	−	Rh_2rh	12.2	+	+	+	R^2r, R^2R^0 or R^0r''
								Rh_2Rh_2	2.4	+	−	−	R^2R^2 or R^2r''
			Rh_z	13.4	+	+	−	Rh_1Rh_2	12.9	+	+	−	R^1R^2, R^1r'' or R^2r'
								Rh_zrh	0.2	+	+	+	R^zr, R^zR^0 or R^0r^y
								Rh_zRh_1	0.2	−	+	−	R^zR^1, R^zr' or R^1r^y
								Rh_zRh_2	0.07	+	−	−	R^zR^2, R^zr'' or R^2r^y
								Rh_zRh_z	0.0004	−	−	−	R^zR^z or R^zr^y
			Rh_z^w	0.6	+	+	+	$Rh_1^w Rh_2$	0.6	+	+	−	$R^{1w}R^2$, $R^{1w}r''$ or $R^2r'^w$
								$Rh_z^w Rh_1$	0.008	−	+	−	$R^{1w}R^z$, $R^{1w}r^y$ or $R^zr'^w$

(For references see pages 633–634)

Table 15 The Rh genotypes of English people (from RACE et al.[48])

Calculated group frequency (if only first 4 sera used) %	Reaction with the 4 antisera fairly widely available: CC^w	c	D	E	Reaction with rarer antisera: pure C	pure C^w	e	f	d	Genetic and antigenic constitution	Short symbols: much used	WIENER and WEXLER[47]	Calculated genotype frequency %
15.1020	−	+	−	−	−	−	+	+	+	cde/cde	rr	rr	15.1020
2.0609	−	+	+	−	−	−	+	+	+	cDe/cde	R_0r	R^0r	1.9950
					−	−	+	+	−	cDe/cDe	R_0R_0	R^0R^0	0.0659
0.9376	−	+	−	+	−	−	+	+	+	cdE/cde	$R''r$	$r''r$	0.9235
					−	−	−	−	+	cdE/cdE	$R''R''$	$r''r''$	0.0141
14.0769	−	+	+	+	−	−	−	−	−	cDE/cDE	R_2R_2	R^2R^2	1.9906
					−	−	−	−	+	cDE/cdE	R_2R''	R^2r''	0.3353
					−	−	+	+	−	cDE/cDe	R_2R_0	R^2R^0	0.7243
					−	−	+	+	+	{ cDE/cde	R_2r	R^2r	10.9657
										{ cDe/cdE	R_0R''	R^0r''	0.0610
0.7644	+	+	−	−	+	−	+	+	+	Cde/cde	$R'r$	$r'r$	0.7644
					−	+	+	+	+	C^wde/cde	R'^wr	r'^w	0.0000
34.8899	+	+	+	−	+	−	+	+	−	CDe/cDe	R_1R_0	R^1R^0	2.0922
					+	−	+	+	+	{ CDe/cde	R_1r	R^1r	31.6759
										{ cDe/Cde	R_0R'	R^0r'	0.0505
					−	+	+	+	−	C^wDe/cDe	$R_1^wR_0$	$R^{1w}R^0$	0.0664
					−	+	+	+	+	{ C^wDe/cde	R_1^wr	$R^{1w}r$	1.0049
										{ C^wde/cDe	R'^wR_0	r'^wR^0	0.0000
0.0234	+	+	−	+	+	−	+	−	+	cdE/Cde	$R''R'$	$r''r'$	0.0234
					+	−	+	+	+	CdE/cde	R_yr	r^yr	0.0000
					+	−	−	−	+	CdE/cdE	R_yR''	r^yr''	0.0000
					−	+	+	−	+	C^wde/cdE	R'^wR''	r'^wr''	0.0000
13.4178	+	+	+	+	+	−	+	−	−	CDe/cDE	R_1R_2	R^1R^2	11.5000
					+	−	+	+	−	cDe/CDE	R_0R_z	R^0R^z	0.0125
					+	−	+	−	+	{ CDe/cdE	R_1R''	R^1r''	0.9685
										{ cDE/Cde	R_2R'	R^2r'	0.2775
					+	−	+	+	+	{ CDE/cde	R_zr	R_zr	0.1893
										{ CdE/cDe	R_yR_0	r^yR^0	0.0000
					+	−	−	−	−	cDE/CDE	R_2R_z	R^2R^z	0.0687
					+	−	−	−	+	{ cdE/CDE	$R''R_z$	$r''R^z$	0.0058
										{ CdE/cDE	R_yR_2	r_yR^2	0.0000
					−	+	+	−	−	C^wDe/cDE	$R_1^wR_2$	$R^{1w}R^2$	0.3648
					−	+	+	−	+	{ C^wDe/cdE	R_1^wR''	$R^{1w}r''$	0.0307
										{ C^wde/cDE	R'^wR_2	r'^wR^2	0.0000
0.0097	+	−	−	−	+	−	+	−	+	Cde/Cde	$R'R'$	$r'r'$	0.0097
					+	+	+	−	+	C^wde/Cde	R'^wR'	r'^wr'	0.0000
					−	+	+	−	+	C^wde/C^wde	$R'^wR'^w$	$r'^wr'^w$	0.0000
18.5073	+	−	+	−	+	−	+	−	−	CDe/CDe	R_1R_1	R^1R^1	16.6097
					+	−	+	−	+	CDe/Cde	R_1R'	R^1r'	0.8016
					+	+	+	−	−	CDe/C^wDe	$R_1R_1^w$	R^1R^{1w}	1.0539
					+	+	+	−	+	{ C^wDe/Cde	R_1^wR'	$R^{1w}r'$	0.0254
										{ C^wde/CDe	R'^wR_1	r'^wR^1	0.0000
					−	+	+	−	−	C^wDe/C^wDe	$R_1^wR_1^w$	$R^{1w}R^{1w}$	0.0167
					−	+	+	−	+	C^wde/C^wDe	$R'^wR_1^w$	r'^wR^{1w}	0.0000
0.2101	+	−	+	+	+	−	+	−	−	CDe/CDE	R_1R_z	R^1R^z	0.1985
					+	−	+	−	+	{ Cde/CDE	$R'R_z$	$r'R^z$	0.0048
										{ CdE/CDe	R_yR_1	r^yR^1	0.0000
					+	−	−	−	−	CDE/CDE	R_zR_z	R^zR^z	0.0006
					+	+	+	−	−	C^wDe/CDE	$R_1^wR_z$	$R^{1w}R^z$	0.0062
					+	−	−	−	+	CdE/CDE	R_yR_z	r^yR^z	0.0000
					+	+	+	−	+	{ CdE/C^wDe	$R_yR_1^w$	r^yR^{1w}	0.0000
										{ C^wde/CDE	R'^wR_z	r'^wR^z	0.0000
0.0000	+	−	−	+	+	−	+	−	+	CdE/Cde	R_yR'	r^yr'	0.0000
					+	−	−	−	+	CdE/CdE	R_yR_y	r^yr^y	0.0000
					+	+	+	−	+	CdE/C^wde	$R_yR'^w$	$r^yr'^w$	0.0000

Table 16

Gene complexes		Antigens				
R_0	*cDe*	D	G	c	ce	e
R_1	*CDe*	D	G	C	Ce	e
R_2	*cDE*	D	G	c	?	E
R_z	*CDE*	D	G	C	CE	E
r	*cde*	—	—	c	ce	e
R'	*Cde*	—	G	C	Ce	e
R''	*cdE*	—	—	c	?	E
R_y	*CdE*	—	G	C	CE	E
R_1^w	C^wDe	D	G	C^w	?	e
R_0^u	cD^ue	(D)	(G)	c	ce	e
r^s	cde^s	—	—	c	ce^s	e^s
R_0^s	cDe^s	D	G	c	ce^s	e^s
R'^s	Cde^s	—	G	C	ce	e^s
	—D—	D	G	—	—	—
	C^wD—	D	G	(C^w)	—	—
	cD—	D	G	(c)	(ce)	—
	— — —	—	—	—	—	—
r^G	(*C*)*d*(*e*)	—	G	(C)	—	(e)

eventual solution of the genetic problems and simply indicates the phenotype Thus Rh. 1, 2, −3, 4, 5 denotes a blood giving the following reactions anti-D+, anti-C+, anti-E−, anti c+, anti e+ (in the nomenclature of FISHER and RACE CDe/cde, in that of WIENER Rh₁rh) The designations of the most important antigens of the Rh blood groups under the three systems of nomenclature are given in Table 17 (mainly from ROSENFIELD et al [59]).

Table 17

ROSENFIELD et al.	FISHER and RACE (CDE)	WIENER (Rh–Hr)	ROSENFIELD et al.	FISHER and RACE (CDE)	WIENER (Rh–Hr)	ROSENFIELD et al.	FISHER and RACE (CDE)	WIENER (Rh–Hr)
Rh1	D	Rh_0	Rh10	V, ce^s	hr^v	Rh19		hr^s
Rh2	C	rh'	Rh11	E^w	rh^{w2}	Rh20	VS, e^s	
Rh3	E	rh''	Rh12	G	rh^G	Rh21	C^G	
Rh4	c	hr'	Rh13	*	Rh^A	Rh22	CE	
Rh5	e	hr''	Rh14	*	Rh^B	Rh23	Wiel, D^w	
Rh6	f, ce	hr	Rh15	*	Rh^C	Rh24	E^T	
Rh7	Ce	rh_i	Rh16	*	Rh^D	Rh25	LW	
Rh8	C^w	rh^{w1}	Rh17	**	Hr_0	Rh26		
Rh9	C^x	rh^x	Rh18		Hr	Rh27	cE	

* Corresponds to some of the apparent anti D formed by anti-D individuals

** Corresponds to an antibody formed by D / D – and other individuals.

The Lutheran blood-group system (CALLENDER and RACE, 1946 [39])

This system is determined by the two allelic genes Lu^a and Lu^b The corresponding antigens Lu^a and Lu^b react with the antibodies anti Lu^a (CALLENDER and RACE [39]) and anti Lu^b (CUTBUSH and CHANARIN [61]) respectively The following phenotypes are possible Lu(a+b−), Lu(a+b+) and Lu(a−b+), corresponding to the genotypes Lu^aLu^a, Lu^aLu^b and Lu^bLu^b CRAWFORD et al [62] describe [illegible]

[illegible]

the genes of the Lutheran groups and those determining the secretion of the ABH blood group substances

The Kell blood-group system (COOMBS et al, 1946 [65])

The discovery of the antibody anti K by COOMBS et al [65] was followed by the description (LEVINE et al [66]) of the antithetic antibody anti k The simple Kell system, with the phenotypes K+k−, K+k+ and K−k+, became more complicated with the finding of the antibodies anti-Kp^a and anti Kp^b (ALLEN and LEWIS [67]) In addition a phenotype was found giving negative reactions with all four Kell antibodies K−k−Kp(a−b−) (CHOWN et al [68]), designated by the symbol K^0. The antibody anti Ku (CORCORAN et al [69]) reacts with all bloods except the very rare K^0 blood A further and [illegible]

[illegible]

Table 18

K	K1 (Kell)
k	K2 (Cellano)
Kp^a	K3 (Penney)
Kp^b	K4 (Rautenberg)
Ku	K5 (Peltz)
Js^a	K6 (Sutter)
Js^b	K7 (Js^b = Matthews)

Present knowledge of the Kell blood-group system is summarized in Table 19 (with slight modification from ALLEN and ROSENFIELD [73]) This does not take account of the relationship with the Js system

Table 19

Designation	Designation according to ALLEN and ROSENFIELD [73]	Antigenic structure of the phenotypes forming the antisera: anti K K1	anti-k K2	anti-Kp^a K3	anti Kp^b K4	anti Ku K5
K+	K 1, 2, −3, 4, 5	+	+	—	+	+
K−	K 1, 2, −3, 4, 5	—	+	—	+	+
k−	K 1, 2, −3, 4, 5	+	—	—	+	+
Kp(a+)	K −1, 2, 3, 4, 5	—	+	+	+	+
K+Kp(a+)	K 1, w 2, 3, 4, 5	+	w	+	+	+
Kp(b−)	K −1, w 2, 3, 4, 5	—	w	+	—	+
K^0	K −1, −2, −3, −4, −5	—	—	—	—	—
McLeod	K 1, w 2, −3, w 4, −5	—	w	—	w	—

w = weak reaction

The secretor character for ABH substances

Secretors and nonsecretors

[illegible]

Table 20

Reaction with anti-Le^a	Reaction with anti-Le^b	Phenotypes
+	–	Le(a+b–)
–	+	Le(a–b+)
–	–	Le(a–b–)
+	+	Le(a+b+)*

* In individuals of groups 0 and A_2.

The Lewis antigens are primarily substances present in the saliva and serum (Grubb[79]), and the erythrocytes obtain them by absorption from the latter (Sneath and Sneath[80]). Since the Lewis phenotype depends on the secretor genotype, a nonsecretor (*se se*) inheriting the Lewis gene *Le* has blood of the Lewis phenotype Le(a+b–), while under the same circumstances the blood of a secretor (*Se se* or *Se Se*) will be Le(a–b+). The prominence of the Lewis phenotype is also affected by the AB0 group of the blood. Thus the A_1 gene interferes with both the Le^b (Andresen[77]) and Le^a (Cutbush et al.[81]) antigens (cf. Table 20). The genetic relationships between the Lewis groups of the erythrocytes and the secretion of Lewis and ABH substances in the saliva have been studied by Grubb[79] and by Ceppellini[82]; their views are summarized in Table 21.

Table 21

Genotype	Antigens in saliva: ABH	Le^a	Le^{bL}	Le^{bH}	Antigens on erythrocytes
Se Se Le Le *Se Se Le le* *Se se Le Le* *Se se Le le*	+	+	+	+	Le(a–b+)
se se Le Le *se se Le le*	–	+	–	–	Le(a+b–)
Se Se le le *Se se le le*	+	–	–	+	Le(a–b–)
se se le le	–	–	–	–	Le(a–b–)

The Duffy blood-group system (Cutbush et al., 1950[83])

The antibodies anti-Fy^a (Cutbush et al.[83]) and anti-Fy^b (Ikin et al.[84]) react respectively with the human erythrocyte antigens Fy^a and Fy^b. The latter are determined by a pair of allelic genes *Fy^a* and *Fy^b*. Sanger et al.[85] described the phenotype Fy(a–b–), of common occurrence among negroes as well as the Jewish population of the Yemen. The Duffy blood groups are summarized in Table 22.

Table 22

Reaction with anti-Fy^a	Reaction with anti-Fy^b	Phenotype	Genotype
+	–	Fy(a+b–)	*Fy^{a}Fy^a*
+	+	Fy(a+b+)	*Fy^{a}Fy^b*
–	+	Fy(a–b+)	*Fy^{b}Fy^b*
–	–	Fy(a–b–)	*FyFy*

The Kidd blood-group system (Allen et al., 1951[86])

The antibodies anti-Jk^a (Allen et al.[86]) and anti-Jk^b (Plaut et al.[87]) react respectively with the human erythrocyte antigens Jk^a and Jk^b, determined by the allelic genes *Jk^a* and *Jk^b*. In the Kidd groups individuals have likewise been found whose blood reacts neither with anti-Jk^a nor with anti-Jk^b, i.e., of phenotype Jk (a–b–). The serum of such persons may contain the antibody anti-Jk^{a}Jk^b (Pinkerton et al.[88]). The Kidd blood groups are summarized in Table 23.

Table 23

Reaction with anti-Jk^a	Reaction with anti-Jk^b	Phenotype	Genotype
+	–	Jk(a+b–)	*Jk^{a}Jk^a*
+	+	Jk(a+b+)	*Jk^{a}Jk^b*
–	+	Jk(a–b+)	*Jk^{b}Jk^b*
–	–	Jk(a–b–)	*JkJk*

The Diego blood-group system (Layrisse et al., 1955[89])

Anti-Di^a, first found in Venezuela by Layrisse et al.[89], de[fines] an antigen Di^a so far detected on the erythrocytes of mongo[loid] peoples, particularly the South American Indians. Anti-Di^b [has] also been described (Thompson et al.[90]).

The Auberger blood-group system (Salmon et al., 1961[91])

The antibody anti-Au^a has been found only once (Salmon et al. The antigen Au^a is equally common among whites and negr[oes]

The Dombrock blood-group system (Swanson et al., 1964[92])

Swanson et al.[92] described the antibody anti-Do^a, reacting w[ith] a hitherto unknown erythrocyte antigen Do^a present in about tw[o] thirds of the bloods tested.

The Ii blood-group system (Wiener et al., 1956[93])

Anti-I is formed by those individuals whose erythrocytes ca[rry] the very small quantities of the antigen I (Wiener et al.[93]). Ant[i-I] consists either of autoantibodies or of rare, naturally occurri[ng] iso-antibodies of cold type. Cord-blood erythrocytes react on[ly] weakly with anti-I; the normal antigenic reaction develops gra[d]ually and reaches the adult level at 18 months. Anti-i was di[s]covered by Marsh and Jenkins[94]. There are various degrees [of] prominence among I carriers. A distinction is also made betwe[en] i_1 (rare among whites) and i_2 (rare among negroes). A connectio[n] between the I and i characters and the AB0 blood groups is likel[y] (Tippett et al.[95]).

The Xg blood-group system (Mann et al., 1962[96])

The Xg blood group is of particular genetic interest as the onl[y] one so far known that is inherited through the X chromosome. Th[e] antibody Xg^a is very rare. The antigen Xg^a, located on the shor[t] arm of the X chromosome, has contributed greatly to new knowl[edge] edge of the topography of this chromosome.

The Yt blood-group system (Eaton et al., 1956[97])

An antibody reacting with 99.6% of English bloods was discovered by Eaton et al.[97] and named by them anti-Yt^a. Anti-Yt^b, which reacts with about 8% of bloods, was described by Giles and Metaxas[98].

Antigens of infrequent occurrence (private antigens)

Antibodies have repeatedly been found which react with antigens often confined to a single family. The genetic classification of the genes corresponding to these family antigens presents difficulty, and usually it is only possible to demonstrate their serological independence of the blood-group characters described above in this chapter and of other individual, private or family antigens. The hereditary character of most of these antigens has been established, namely Levay[39], Jobbins[99], Becker[100], Ven[101], Wr^a[102], Be^a[103], Rm[20], By[104], Chr^a[105], Sw^a[106], Good[107], Bi[108], Tr^a[109]. In others, inheritance has not been proved, namely Stobo[110], Ot[111], Ho[112], Price[113] and the antigens of the Bennett, Goodspeed, Sturgeon and Donna groups[114].

Widely distributed antigens (public antigens)

These are antigens whose absence from human erythrocytes is an extremely rare occurrence. Examples are Vel[115], Ge[116], Lan[117] and Sm[117].

Clinical significance of the blood groups

Blood-group specific antibodies may bring about haemolytic reactions during blood transfusions or be the cause of haemolytic disease of the newborn. The most important and most widely distributed of the blood-group specific antibodies and their role in the causation of the haemolytic transfusion reaction (*HTR*) and haemolytic disease of the newborn (HDN) are summarized in Table 2[4]

Table 24 Clinical importance of the blood-group specific antibodies (adapted from METAXAS[1178])

Blood group system	Antibody	HTR	HDN
AB0	anti-A	Yes	Yes
	anti-B	Yes	Rare
	anti-A_1	Very rare	No
	anti-H	No	No
MNSs	anti-M	Very rare	Very rare
	anti-N	No	No
	anti-S	Very rare	Rare
	anti-s	Very rare	Rare
	anti-U (S+s)	Very rare	Very rare
P	anti-P_1	Very rare	No
Rh	anti-D	Yes	Yes
	anti-C	Yes	Rare
	anti-c	Yes	Yes
	anti-C^w	Yes	Rare
	anti-E	Yes	Yes
	anti-e	Rare	Very rare
Lutheran	anti-Lu^a	No	No
	anti-Lu^b	Yes	Very rare

Blood group system	Antibody	HTR	HDN
Kell	anti-K	Yes	Yes
	anti-k	Very rare	Very rare
	anti-Kp^a	No	No
	anti-Kp^b	No	Very rare
	anti-Js^a	Rare	No
Lewis	anti-Le^a	Yes	No
	anti-Le^b	Rare	No
	anti-X (Le^a+Le^b)	Yes	No
Duffy	anti-Fy^a	Yes	Very rare
	anti-Fy^b	?	No
Kidd	anti-Jk^a	Yes	Rare
	anti-Jk^b	Rare	Very rare
	anti-Jk^aJk^b	Rare	?
Diego	anti-Di^a	Yes	?
Auberger	anti-Au^a	?	?

Serum groups[1]

Some serum proteins exhibit a genetically determined allotypy that allows serum groups to be distinguished. Such proteins include the γ-globulins (Gm groups), the α_2-globulins (haptoglobins and Gc groups), the lipoproteins (Ag, Lp and Ld groups), the transferrins and serum cholinesterase. Polymorphism occurs not only among the serum enzymes but also among those of the erythrocytes, such as acid phosphatase[26], phosphoglucomutase[27], esterases[28] and lactate dehydrogenase[29].

Gm serum groups (GRUBB and LAURELL[2]) (genetic factors of the immune globulins)

The Gm serum groups are determined by the Gm factors located on the H chain and the Inv factors located on the L chain of the immune globulins (see also page 581). The Gm and Inv factors can be detected by means of the agglutination-inhibition reaction with Rh-positive erythrocytes carrying incomplete anti-D antibodies. A further character of the immune globulins, located on the H chain of the γ_{2b} type and independent of the Gm and Inv factors, is detected by a serum known as anti-ISf. So far, 22 Gm and 3 Inv characters have been described. The most important Gm factors are Gm^a (GRUBB and LAURELL[2]), Gm^b (HARBOE[3]), Gm^x (HARBOE and LUNDEVALL[4]) and Gm^t (GOLD et al.[5]). In 1965 a new nomenclature was proposed under which these Gm factors would become Gm(1), Gm(5), Gm(2) and Gm(4) respectively, while the original Inv(l) factor would be redesignated Inv(1).

Haptoglobin groups (SMITHIES[6])

When the α_2-globulins are separated electrophoretically in starch gel the haptoglobin bands show group-specific differences. These allow three Hp phenotypes to be distinguished, corresponding to three genotypes (Table 1).

Table 1

Phenotype	Genotype
Hp 1–1	Hp^1/Hp^1
Hp 2–1	Hp^1/Hp^2
Hp 2–2	Hp^2/Hp^2

Haptoglobins are normally absent from the blood of the newborn. Ahaptoglobinaemia may also result from intravascular haemolysis. True ahaptoglobinaemia, a defect in the blood proteins, is extremely rare.

A few rare variants of the haptoglobin groups have been reported, such as Hp-Ca (GALATIUS-JENSEN[7]) and the Johnson type (GIBLETT[8]); the latter occurs in two different modifications (1 and 2).

Group-specific components (Gc groups) (HIRSCHFELD[9])

By immunoelectrophoretic separation of the α_2-globulins HIRSCHFELD[9] was able to show that these proteins exhibited an allotypy he designated Gc grouping. A rapidly migrating Gc-1-1 type is distinguished from an intermediate Gc-2-1 type and a slowly migrating Gc-2-2 type.

Corresponding to these phenotypes are three genotypes owing their existence to the autosomal genes Gc^1 and Gc^2: Gc^1Gc^1, Gc^1Gc^2 and Gc^2Gc^2. Very rare variants are Gc^x (HIRSCHFELD[10]), Gc^y (HIRSCHFELD[11]) and Gc^z (HENNIG and HOPPE[12]).

Lipoprotein groups (Ag groups [ALLISON and BLUMBERG[13]]; Lp groups [BERG[14]])

In the complex class of lipoproteins a distinction is made between *high-density lipoproteins and low-density lipoproteins (LDL).* The latter also show a genetically determined allotypy th: demonstrated by means of precipitating immune sera. ' precipitating anti-LSL antibody was found by ALLISON an BERG[13] in the serum of a patient who had received a large of blood transfusions and named by them anti-Ag. Iso-pr with anti-Ag specificity were also found in the blood of wor had had at least four pregnancies (DÜRWALD et al.[15]). Va specificities have since been described in addition to the Ag(a)[13], namely Ag(b)[16], Ag(x)[17], Ag(a_1)[18] and Ag(z)[18]. I cently, BERG[19] has proposed the designation Ld(a) for yet Ag specificity.

It has not proved possible to produce a heterospecific serum from animals, though by immunizing rabbits BER tained heterospecific anti-LDL sera reacting with a furth antigen, Lp. The genetic independence of the Ag and Lp ch appears to have been confirmed[19]. Isoimmunization again factor has not yet been reported. An anti-Lp serum has al produced from horses[20]. Whereas the original anti-Lp defined the factor Lp(a), the heterospecific anti-Lp horse s reacts with the factor Lp(x).

Transferrin groups (SMITHIES[21])

The transferrin groups (Tf groups) are due to polymorp the iron-binding β_1-globulin transferrin (siderophilin). Up types of transferrin distinguished by their different electrop mobilities are known (SMITHIES and HILLER[22], GIBLETT e Each transferrin corresponds to an autosomal gene, of whi individual possesses a pair. Most members of the white r homozygotic for the gene Tf^c.

Cholinesterase groups (LEHMANN and RYAN[24], KALOW a GENEST[25])

Group-specific differences in the activity of the serum cholinesterase give rise to the cholinesterase groups. Their interpretation is still obscure.

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Cerebrospinal Fluid

(For references see pages 639–640)

Unless otherwise stated, the following data apply to the lumbar fluid of adults drawn from the spinal subarachnoid space between the 3rd and 4th lumbar vertebrae. As a result of variations in the secretory, transudatory and resorptive processes there are some differences in the composition of the fluid in the various spaces, i e., between that of lumbar fluid, cisternal fluid and ventricular fluid. For further details the reader is referred to the specialized literature[1–6].

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Physicochemical data					
Pressure (mm Hg)					
Children	–	(3 0–7.5)	–	5	Determined with the subject lying on his side Measured values are affected by the position of the subject, by breathing and by the heart beat The pressure is increased by inhalation of CO_2 and by alkalosis, decreased by inhalation of O_2 and hyperventilation[7] *Queckenstedt test* the pressure is increased on compression of both jugular veins and returns to normal as soon as the compression is released If the pressure of the spinal fluid increases on compression of a single jugular vein, this indicates thrombosis of the lateral venous sinus on the opposite side
Adults	–	(4 5–13 5)	–	5	
Volume (ml)					
Infants	–	(40–60)	–	6	In adults the volume is made up of about 35 ml in the ventricles, 25 ml in the subarachnoid space and the cisternae, and 75 ml in the spinal canal
Young children	–	(60–100)	–	6	
Older children	–	(80–120)	–	6	
Adults	135	(100–160)	–	5	
Appearance					—
					cent
Leucocyte count (per µl)					
Newborn (0–14 days)					
Lumbar fluid	7 5	(0–15)	–	8	Val
Adults					
(a) Lumbar fluid	1 1	0–5 3	–	9	
(b) Cisternal fluid	0 9	0–3 6	–	9	
(c) Ventricular fluid	–	(0–1)	–	10	
Erythrocyte count (per µl)					
Newborn (0–14 days)	120	(0–675)	–	8	Exc indi can
Specific gravity	1 0070	(1 006 2–1 008 2)	–	11	Val
Freezing-point depression (°C)	0 569	(0 540–0 603)	–	12	Val spir
Osmolality (mosm/kg H_2O)	306	–	–	13	
Refractive index	–	(1 334 94–1 335 10)	–	14	
Surface tension (20 °C, dyn cm^{-1})	61 5	60 0–63 0	0 75	15	Mea
Relative viscosity (38 °C)	–	(1 020–1 027)	–	16	
Specific conductivity (18 °C, S cm^{-1})	0 011 90	–	–	17	
Dry substance (g/kg)	10 8	(8 5–17 0)	–	11	Val
pH value					
Cisternal fluid	7 349	7.327–7 371	0 011	18	

Cerebrospinal Fluid

(For references see pages 639–640)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
‹anolamine (mg/l)	–	(0 5–1.5)	–	40	The spinal fluid contains more ethanolamine than the serum
‹atine (mg/l)	–	(4 6–18 7)	–	41	
‹atinine (mg/l)	–	(6–14)	–	41	
‹ea (mg/l)	250	(138–364)	–	42	Values from 106 subjects by the urease method The urea concentration of the spinal fluid is about three-quarters of that of the serum[42, 43]. It is increased in diseases accompanied by nitrogen retention
‹ic acid (mg/l)	–	(5–26)	–	5	
‹etylcholine (μg/l)	–	(<20)	–	44	
‹istamine (μg/l)	9.7	(2–30)	–	45	
‹rotonin (μg/l)	1.04	0 66–1.42	0.19	46	Values from 48 subjects by a biological method
‹doxylsulphuric acid (mg/l)	1.0	0 6–1.4	0 2	47	Values from 50 subjects Increased in renal insufficiency
‹ilirubin (mg/l)					
Newborn	2 4	0 4–4 4	1 0	48	Values from 34 newborn infants with a bilirubin serum level of 67 mg/l The bilirubin concentration of the spinal fluid rises with that of the serum (correlation coefficient 0 58[48]) Most of the bilirubin in the spinal fluid is in the unconjugated form[49, 50]
Adults	–	(<0 1)	–	49	
‹roteins (mg/l)					
‹hildren					
‹a) 1–5 days	700	(250–900)	–	51	
‹b) 5–8 months	204	156–252	24	8	
‹dults					
c) Lumbar fluid	244	156–333	44	52	
d) Lumbar fluid	313	123–503	95	53	
e) Cisternal fluid	218	127–310	46	52	
f) Cisternal fluid	183	97–269	43	53	
‹g) Ventricular fluid	171	0–369	99	53	
Mucoproteins (mg/l)	51	15–87	18	60	
Sialic acid (mg/l)	5 1	3 3–6 9	0 9	61	Determined in 15 samples by the thiobarbituric acid method The spinal fluid contains no free sialic acid
β-Lipoproteins (mg/l)	0 39	(0 10–0 62)	0 18	62	Values from 12 subjects

Paper-electrophoretic protein fractions of spinal fluid (as percentages of the total protein)

	Number	Prealbumin		Albumin		α_1-Globulins		α_2-Globulins		β Globulins		γ Globulin		Reference
		Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	
Children (1–5 days)	35	2.5		47.4		6 8		8 8		14 5		20 0		51
Adults														
Lumbar fluid	22	3 4	1 98	54 8	6 95	8 8	0 24	7.9	1 77	{9 8 / 5 8}*	{1.71 / 1 53}*	9 8	2 88	52
	21	4 6	1.3	49 5	6 5	6 7	2.0	8 3	2.1	18 5	4.8	11 2	2.7	53
Cisternal fluid	13	4 6	1 6	44 6	7.3	6 7	1 0	9 5	3 7	21.3	4 5	13 4	4 0	53
Ventricular fluid	7	6.3	1 8	46.4	6 5	8 1	1 7	7.9	2 8	19 1	2 0	10.3	2 7	53

* Total β-fraction, first value β fraction, second value β_1 fraction.

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Carbohydrates and non-nitrogenous metabolites					
Glucose (mg/l)					
(a) Lumbar fluid	615	487–743	64	75	Determined by (a) glucose oxidase method, (b) [illegible]
(b) Lumbar fluid	670	480–860	95	75	
(c) Lumbar fluid	–	(500–800)	–	10	
(c) Cisternal fluid	–	(500–900)	–	10	
(c) Ventricular fluid	–	(500–900)	–	10	
Fructose (mg/l)	34	(24–42)	–	77	
Glucosamine (mg/l)	90	(50–180)	–	78	
Inositol (mg/l)	25 5	13 7–37.3	5 9	79	Values from 14 subjects
Pyruvic acid (mg/l)	–	(4–7)	–	80	Diagnostic use of this assay has been suggested[81]
α-Ketoglutaric acid (mg/l)	–	(0.3–2 9)	–	80	
Oxaloacetic acid (mg/l)	–	(0 8–1.1)	–	80	
Succinic acid (mg/l)	–	(2 8–3 9)	–	82	
Citric acid (mg/l)					
Lumbar fluid	54	–	–	83	Values from 30-year old subjects The citric acid concentration of the spinal fluid increases with age
Cisternal fluid	37	–	–	83	
Lactic acid (mEq/l)	1 6	0 84–2 36	0 38	22	Values by an enzyme method from 23 subjects whose serum lactic acid level was 1 4 mEq/l
Acetoacetic acid (mg/l)	2 67	(1 61–5 46)	1 26	88	Values by an enzyme method from 11 subjects
β Hydroxybutyric acid (mg/l)	4 83	(2 47–9 80)	2 49	88	Values by an enzyme method from 11 subjects
Vitamins					
Thiamine (µg/l)					
(a)	–	(13–17)	–	84	Values from (a) 45 subjects with *Ochromonas malhamensis*, (b) 36 subjects with *Ochromonas danica* In the spinal fluid thiamine occurs in both the free and phosphorylated form[1]
(b)	4	(3–12)	–	85	
Vitamin B_6 (µg/l)	–	(0–0 75)	–	84	Determined with *Tetrahymena pyriformis*
Nicotinic acid (mg/l)	–	(0 1–0 5)	–	1	
Folic acid (µg/l)					
(a)	–	(10–30)	–	86	Determined with (a) *Lactobacillus casei*, (b) *Pediococcus cerevisiae* For methods see page 478
(b)	–	(1–5)	–	88	
Vitamin B_{12} (ng/l)	–	(0–30)	–	86	Determined with *Ochromonas malhamensis*
Pantothenic acid (mg/l)	0 52	(0 10–1 7)	–	84	Values from 103 subjects determined with *Lactobacillus plantarum* Present mainly in the combined form
Ascorbic acid (mg/l)	–	(3–21)	–	1	Present in the reduced form

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2 [illegible]

8

9

10

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Enzymes*	...	...	...	...	About 30 enzymes have so far been identified in the spinal fluid[4,6]. In ad to those listed, *the spinal fluid contains* various esterases (e.g., cholinest lipases, ribonuclease, isocitrate dehydrogenase and succinate dehydrog There is no direct relationship between the enzyme activity of the seru that of the spinal fluid. Disturbances of the permeability of the blood and blood-spinal fluid barriers may result in transudation of enzymes fr serum and cerebral parenchyma into the spinal fluid.
1.1.1.14 **L-Iditol dehydrogenase** (U/l, 25 °C)	1.0	0.54–1.46	0.23	63	Values from children aged 2–15 years.
1.1.1.27 **Lactate dehydrogenase** (U/l, 25 °C)	18.4	6.8–30.0	5.8	64	The proportions of the individual isoenzymes in the spinal fluid are mu same as in the serum[65]. No significant age differences have been obser children[63].
1.1.1.37 **Malate dehydrogenase** (U/l, 25 °C)	20.8	12.8–28.8	4.0	64	
2.1.3.3 **Ornithine carbamoyltransferase** (U/l, 37 °C)	0.31	0.05–0.57	0.13	66	Values from 77 children.
2.6.1.1 **Aspartate aminotransferase** (U/l, 25 °C)	–	(0–10)	–	67	Determined spectrophotometrically. Significant age differences have not observed in children[63].
2.6.1.2 **Alanine aminotransferase** (U/l, 25 °C)	–	(0–9)	–	67	
3.4.1.1 **Leucine aminopeptidase** (U/l, 37 °C)	0.17	(0.05–0.28)	–	68	
4.1.2.13 **Fructose diphosphate aldolase** (U/l, 37 °C)	0.29	0–0.73	0.22	64	
5.3.1.6 **Ribose phosphate isomerase** (U/l, 37 °C)	1.2	(0.5–1.3)	–	69	
5.3.1.9 **Glucose phosphate isomerase** (U/l, 37 °C)	15	(2.5–38)	–	69	
Lipids					
Total lipids (mg/l)	12.52	7.66–17.4	2.43	59	The spinal fluid contains triglycerides, phospholipids, cholesterol and ch teryl esters. The fatty acid composition of the spinal fluid lipids is qualitat similar to that of the plasma lipids; the proportion of linoleic acid in the s fluid fatty acids (4%) is lower than that in the plasma fatty acids (24%)
Neutral fats (mg/l)	4.17	0–9.01	2.42	59	Calculated by difference. Probably consist mainly of triglycerides.
Cholesterol (mg/l)					
(a)	3.95	2.19–5.71	0.88	59	The proportion of free cholesterol was (a) 33%, (b) 44%.
(b)	4.63	1.55–7.71	1.54	71	
Phospholipids					
(mg/l)	5.49	2.09–8.89	1.70	71	The phospholipids of the spinal fluid consist of lecithins, cephalins, plasn gens, sphingomyelins and small amounts of lysolecithins[55,72]. In ner diseases the phospholipid concentration of the spinal fluid is often increa in diseases accompanied by breakdown of myelin in the nervous tissue cephalin concentration of the spinal fluid is increased[73].
(μmol/l)	5.21	3.41–7.01	0.90	59	
Total fatty acids (μmol/l)	70	42–98	14	74	

* Given are the numbers and trivial names recommended by the Enzyme Commission of the International Union of Biochemistry (see pages 385–386) definition of the unit U see page 584.

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
rbohydrates d non-nitrogenous tabolites					
acose (mg/l)					
Lumbar fluid	615	487–743	64	75	Determined by (a) glucose oxidase method, (b) Folin-Wu method, (c) Hagedorn-Jensen method Glucose can also be determined by the …
Lumbar fluid	670	480–860	95	75	
Lumbar fluid	–	(500–800)	–	10	
Cisternal fluid	–	(500–900)	–	10	
Ventricular fluid	–	(500–900)	–	10	
uctose (mg/l)	34	(24–42)	–	77	
ucosamine (mg/l)	90	(50–180)	–	78	
ositol (mg/l)	25 5	13.7–37.3	5 9	79	Values from 14 subjects.
ruvic acid (mg/l)	–	(4–7)	–	80	Diagnostic use of this assay has been suggested[87]
Ketoglutaric acid (mg/l)	–	(0 3–2 9)	–	80	
aloacetic acid (mg/l)	–	(0 8–1.1)	–	80	
ccinic acid (mg/l)	–	(2 8–3.9)	–	82	
tric acid (mg/l)					
umbar fluid	54	–	–	83	Values from 30-year old subjects The citric acid concentration of the spinal fluid increases with age
sternal fluid	37	–	–	83	
ctic acid (mEq/l)	1 6	0 84–2 36	0 38	22	Values by an enzyme method from 23 subjects whose serum lactic acid level was 1 4 mEq/l
cetoacetic acid (mg/l)	2.67	(1 61–5 46)	1 26	88	Values by an enzyme method from 11 subjects.
Hydroxybutyric acid (mg/l)	4 83	(2 47–9 80)	2 49	88	Values by an enzyme method from 11 subjects.
itamins					
hiamine (µg/l)					
)	–	(13–17)	–	84	Values from (a) 45 subjects with *Ochromonas malhamensis*, (b) 36 subjects with *Ochromonas danica* In the spinal fluid thiamine occurs in both the free and phosphorylated form[1]
)	4	(3–12)	–	85	
itamin B_6 (µg/l)	–	(0–0 75)	–	84	Determined with *Tetrahymena pyriformis*
icotinic acid (mg/l)	–	(0 1–0 5)	–	1	
olic acid (µg/l)					
)	–	(10–30)	–	86	Determined with (a) *Lactobacillus casei*, (b) *Pediococcus cerevisiae* For methods see page 478
)	–	(1–5)	–	86	
itamin B_{12} (ng/l)	–	(0–30)	–	86	Determined with *Ochromonas malhamensis*
antothenic acid (mg/l)	0 52	(0 10–1 7)	–	84	Values from 103 subjects determined with *Lactobacillus plantarum* Present mainly in the combined form
scorbic acid (mg/l)	–	(3–21)	–	1	Present in the reduced form

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Synovial Fluid

(For references see page 642)

The synovial fluid consists of a serum ultrafiltrate together with a secretion formed by the cells of the synovial membrane; the latter component contains mucopolysaccharides. Normal values for the synovial fluid have been assembled by ROPES and BAUER[1] and by DITTMER[2]. For changes in the composition of the synovial fl joint disease see the literature[1,3,4].

Unless otherwise stated, the data given below refer to sy fluid from the *knee joint*.

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Physical data					
Volume (ml)	1.1	(0.13–4.00)	–	2	Often increased to 10–30 ml in joint disease.
Specific gravity (20 °C/20 °C)	–	(1.0081–1.015)	–	5	Postmortem values in 25 subjects.
Viscosity					
Relative viscosity (37 °C)	–	(>300)	–	6	The viscosity is dependent on the hyaluronic acid content. It is often dimi in joint disease[6,7].
Intrinsic viscosity (37 °C)	46.3	26.9–65.7	9.7	6	
Cells (per µl)	63	(13–180)	–	8	Consist of 63% mononuclear phagocytes, 25% lymphocytes, 6.5% morphonuclear leucocytes and 4% synovial cells; any erythrocytes not arise from injury during aspiration. The various kinds of cell present i fluid in rheumatic diseases have been studied[9].
pH value	7.434	(7.31–7.64)	–	10	Measured in vivo. The pH is lower in inflammatory joint disease.
Water (g/kg)	–	(960–988)	–	5	Postmortem values in 25 subjects.
Dry substance (g/kg)	34	(12–48)	–	2	
Inorganic substances					
Carbon dioxide (mmol/l)	–	(19.3–30.6)	–	11	In accordance with the DONNAN equilibrium the bicarbonate concentration of the synovial fluid is higher than that of the serum[1].
Chloride (mEq/l)	107.4	(87–138)	–	7	In accordance with the DONNAN equilibrium the chloride concentration of the synovial fluid is higher than that of the serum[1].

marks

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...n of the synovial fluid is the same as that
...ed in traumatic degenerative arthritis and

...rdance with the DONNAN equilibrium the
...ovial fluid is lower than that of the serum[7]
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...joint disease[7]

...n accordance with the DONNAN equilibrium
...novial fluid is lower than that of the serum[7].
...) calcium pyrophosphate crystals have been

...uilibrium the magnesium concentration of
...t of the serum[7]

...s Increased in rheumatoid arthritis

...d in rheumatoid arthritis

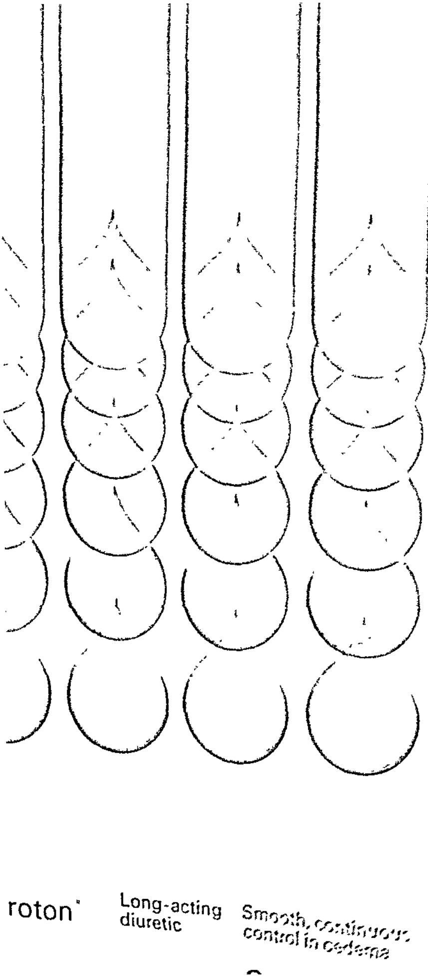
Increased in joint disease as a result of the

total nitrogen

...synovial fluid is roughly equal to that of the
...are often found in the synovial fluid[18].

...ues in the literature, (b) determined in 6 men
...ation of albumin is higher than in the serum,
...portion of α_1-globulins is usually higher than
...haptoglobin content is low[24], and fibrinogen
...sent[25]. The protein concentration is usually
...[23 26 42], especially in rheumatoid arthritis.
...toglobin[24], γ globulin[22 23 42] and caerulo-

...he synovial fluid and include lactate dehydro-
...ase[28 30], isocitrate dehydrogenase[30], gluta-
...minotransferase[28 30], alanine aminotransfer-
...ase[31], β glucuronidase[32], aminopeptidase[33],
...[30] and glucose phosphate isomerase[28 30]
...mes lie within or below their normal ranges
...f many of them are increased in inflammatory



...ulins	α_1-Globulin/ α_2-globulin ratio	Ultracentrifuge 19S	7S	4S	1S
...		%	%	%	%
4	1 0	–	–	–	–
3	1 3	2	12	83	3
1	0 7	3	8	88	1
6	0 5	4	24	72	0
6	0 5	2	12	86	0

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The synovial fluid consists of a s
a secretion formed by the cells of th
component contains mucopolysacc
synovial fluid have been assembled

Physical data

Volume (ml)............

Specific gravity
(20 °C/20 °C)...

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Phosphate	...	...	...	...	The inorganic phosphate concentration of the synovial fluid is the [illegible] that of the serum[7].
Sulphate	..	...	...	...	The inorganic sulphate concentration of the synovial fluid is the same [illegible] *of the serum, but is generally increased in traumatic degenerative arthr[illegible] decreased* in rheumatoid arthritis[12].
Potassium (mEq/l)	4 0	3 5–4.5	0 25	13	Determined in 10 subjects In accordance with the DONNAN equilibri[illegible] potassium concentration of the synovial fluid is lower than that of the [illegible] It shows no characteristic changes in joint disease[7]
Sodium (mEq/l)	136.1	133–139	1 63	13	Determined in 10 subjects In accordance with the DONNAN equilibri[illegible] sodium concentration of the synovial fluid is lower than that of the ser[illegible] shows no characteristic changes in joint disease[7]
Calcium (mEq/l)	–	(2 3–4 7)	–	5	Postmortem values in 25 subjects In accordance with the DONNAN equi[illegible] the calcium concentration of the synovial fluid is lower than that of the [illegible] In chondrocalcinosis (pseudo-gout) calcium pyrophosphate crystals ha[illegible] found in the synovial fluid[14]
Magnesium	..	...		...	In accordance with the DONNAN equilibrium the magnesium concentr[illegible] the synovial fluid is lower than that of the serum[7]
Aluminium (µg/kg)	290	(40–900)	–	15	Postmortem spectrographic values
Iron (µg/kg)	43	(20–90)	–	15	Postmortem spectrographic values
Copper (µg/kg)	210	(40–640)	–	15	Postmortem spectrographic values Increased in rheumatoid arthritis
Rubidium (µg/kg)	540	(110–1300)	–	15	Postmortem spectrographic values
Zinc (µg/l)	373	247–499	63	16	Determined in 6 samples Increased in rheumatoid arthritis
Organic substances					
Total nitrogen (g/l)	–	(0 84–4 0)	–	5	Postmortem values in 25 subjects Increased in joint disease as a resul[illegible] increased protein content
Nonprotein nitrogen (g/l)	–	(0 22–0 43)	–	11	Corresponds to about 10% of the total nitrogen.
Uric acid (mg/l)	73 4	–	–	17	The uric acid concentration of the synovial fluid is roughly equal to th[illegible] serum In gout, uric acid crystals are often found in the synovial fluid
Protein (g/l)					
(a)	17 2	(4 5–31 5)	–	2	[illegible]
(b)	12	(5–18)	–	19	
Enzymes					plasmin[22] fractions [illegible] ... [illegible] concentrations of these enzymes lie within or below their norma[illegible] in the serum, the concentrations of many of them are increased in inflam[illegible] joint disease

Protein fractions in the synovial fluid (and serum)[42]

	Volume per knee joint	Biuret reaction	Paper electrophoresis at pH 8 6					α_1-Globulin/ α_2-globulin ratio	Ultracentrif[illegible]		
			Albumin	α_1-Globulins	α_2 Globulins	β Globulins	γ-Globulins		19S	7S	4S
	ml	g protein/l	%	%	%	%	%		%	%	%
Synovial fluid											
Normal	0.2–0 4	18	63	7	7	9	14	1.0	–	–	–
Post mortem	7	18	50	9	7	12	23	1 3	2	12	83
Traumatic	10	26	55	5	8	11	21	0 7	3	8	88
Rheumatoid arthritis	–	45	45	5	10	14	26	0 5	4	24	72
Serum											
Normal	–	70	49	6	12	17	16	0 5	2	12	8[illegible]

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Reducing substances (glucose)	...	...	...	...	The glucose concentration of the synovial fluid is about the same as that o[f] serum in health but lower in inflammatory joint disease (see table below)
Hyaluronic acid (g/l)	3.21	2.45–3.97 (2.50–3.65)	0.38	34	Determined in 8 subjects as hexuronic acid. The hyaluronate normally [con]tains 2% of protein[35], that from pathological effusions 10%[26]. In j[oint] disease the hyaluronate concentration is usually *lowered*[6,7,23,26,34]. The deg[ree] of polymerization of the hyaluronate is *lowered* in inflammatory joint disease; this results in a lowering of the intrinsic viscosity of the synovial fluid an[d is] responsible for the pathological result in the mucin test (see table below).
Sialic acid (g/l)	0.28	0.14–0.42	0.07	37	Determined in 10 samples by the diphenylamine reaction.
Lactic acid	...	...	...	...	The lactic acid concentration of the synovial fluid is the same as that of serum but is increased in inflammatory joint disease[1,38].
Ascorbic acid (mg/l)	–	(1.5–11.6)	–	39	Measured in 6 patients with rheumatoid arthritis.
Lipids	...	...	...	...	In joint disease the lipid concentration of the synovial fluid is about 10 ti[mes] greater than normal[40,41].
Cholesterol (mg/l)	71	–	–	41	
	–	(50–140)	–	21	
Phospholipids (mg/l)	138	(130–150)	–	41	
Triglycerides (mg/l)	0	–	–	41	

Synovial fluid in joint disease[4]

	Normal	Noninflammatory	Inflammatory	Septic	Haemorrhagi[c]
Volume (ml)	<3.5	>3.5	>3.5	>3.5	>3.5
Appearance	clear, colourless	straw-yellow, clear	cloudy, yellow	cloudy, yellow	bloody
Viscosity	high	high	low	low	variable
Fibrin clot	absent	usually absent	present	present	usually absen[t]
Mucin clot*	strong	strong	friable	friable	variable
Nucleate cells per microlitre	<200	200–5000	2000–100000	20000–200000	200–10000
Polymorphonuclear leucocytes in nucleate cells (%)	<25	<25	>50	>75	<50
Difference between glucose contents of blood and synovial fluid (mg/l)	<100	<100	>250	>250	<250
Cultures	negative	negative	negative	often positive	negative

* After addition of acetic acid.

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Saliva

(For references see page 646)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Phosphorus (mg/l)					
Parotid saliva					
(a) Inorganic phosphorus ...	201	14–388 (90–420)	93.5	9	Values from (a) 42, (b) 28, (c) 120, (d) 50, (e) 180 subjects. The inorgan phosphate content falls with increasing rate of secretion[2]. Most of the organ phosphorus is acid-soluble and contains phosphoethanolamine[21] as well adenosine phosphates, sugar phosphates and phosphoglyceric acid[22]; t acid-insoluble fraction contains traces of phospholipids[20].
Submandibular saliva					
(b) Inorganic phosphorus ...	148	26–270 (70–350)	61	9	
Total saliva					
(c) Total phosphorus.......	204	120–288	42	20	
(d) Organic phosphorus	55	0–133	39	20	
(e) Inorganic phosphorus ...	149	81–217	34	20	
Sulphur (mg/l)............	–	(30–200)	–	23	Values from 5 subjects. Most of the sulphur is probably present in the form c thiocyanate.
Bromide (mg/l)...........	–	(0.2–7.1)	–	24	
Fluoride (mg/l)...........	–	(0.08–0.25)	–	4	The fluoride content of saliva appears to be independent of that of the drinkin water.
Iodide (mg/l).............	0.102	0.002–0.202 (0.035–0.240)	0.05	25	In men most of the iodine present in saliva is in the form of iodide[26]. Th iodine content of the saliva is 7–100 times higher than that of the serum; iodin concentration occurs in the parotid and submandibular glands but not in th sublingual glands[26]. The highest iodide concentration is associated with lo rates of secretion[27,28]. The relationship between iodine concentration in th saliva and thyroid function has been studied[29].
Thiocyanate (mg/l)........	113	0–257 (24–380)	72	30	Values from 37 nonsmokers; mean value in smokers 321 mg/l. Like iodid thiocyanate is preferentially secreted by the salivary glands. The thiocyanat content of parotid saliva falls with increasing rate of secretion[27].
Potassium (mEq/l)					
(a) Parotid saliva...........	25.1	11.7–38.5 (15–46)	6.7	9	Values from (a) 42, (b) 28, (c) 4 and (d) 9 subjects; values (e) are from childre and adults. In all salivary fractions the potassium content is higher than in th serum. In young children the potassium content is higher than in adults[32], i whom it is largely independent of age and sex[33]. At rates of secretion ove 0.5 ml/min the potassium content is roughly constant, at rates below this figur increased[17,31,34–36]. *The literature contains conflicting data on hourly fluc tuations*[9,31,33,37].
(b) Submandibular saliva....	18.0	6.8–29.2 (10–38)	5.6	9	
(c) Sublingual saliva........	–	(18–40)	–	9	
Total saliva					
(d) Resting saliva	20.7	(14–41)	–	9	
(e) At a minute volume of 2 ml	19	11–27	4	31	
Sodium (mEq/l)					
(a) Parotid saliva...........	6.9	0–15.9 (1.7–17)	4.5	9	Values from (a) 42, (b) 28, (c) 4 and (d) 9 subjects; values (e) are from childre and adults. In all salivary fractions the sodium content is less than that of the serum and rises with increasing rate of secretion[2,17,31,34,35]. In young chil dren, the sodium content is higher than in adults[32], in whom it is largely in dependent of age and sex[33]. The literature contains conflicting data on hourly fluctuations[9,31,33,37]. In children with cystic pancreatic fibrosis the sodium content of the saliva shows a significant increase[38].
(b) Submandibular saliva....	5.1	0.3–9.9 (0.9–10)	2.4	9	
(c) Sublingual saliva........	–	(11–120)	–	9	
Total saliva					
(d) Resting saliva	14.4	(5.2–24.4)	–	9	
(e) At a minute volume of 2 ml	24	12–36	6	31	
Sodium–potassium ratio					
(a) Resting saliva	0.7	–	–	–	(a) Calculated from the sodium and potassium contents of the total saliva; (b) applies to children and adults. Since the potassium content of saliva is largely independent of the rate of secretion whereas the sodium content is proportional to the latter the sodium–potassium ratio necessarily rises with increasing rate of secretion. The sodium and potassium contents of saliva are related to the functioning of the anterior pituitary-adrenocortical system; during treatment with deoxycorticosterone the ratio falls as a result of sodium retention[39], and it is also reduced in primary aldosteronism[40].
(b) At a minute volume of 2 ml	1.35	0.6–2.1	0.375	31	
Calcium (mEq/l)					
Parotid saliva..............	1.5	–	–	41	The calcium content, especially that of the submandibular saliva, rises with increasing rate of secretion[2,42]. An increased calcium content of the sub mandibular saliva has been observed in cystic pancreatic fibrosis[43].
Submandibular saliva.......	–	(3–6)	–	3	
Total saliva	3.1	(2.3–5.5)	–	6	

	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks
Magnesium (mEq/l)					
Parotid saliva	0.6	–	–	9	
Submandibular saliva	0 6	–	–	9	
Total saliva	0.6	(0 16–1 06)	–	6	
Cobalt (µg/l)	–	(0–125)	–	44	Values from the stimulated saliva of 7 subjects, cobalt could be detected i only 10 out of 37 saliva specimens.
Copper (µg/l)	317	(50–760)	151	45	Values from 30 subjects
Nitrogenous constituents					
Total nitrogen (g/l)					
(a) Parotid saliva	0 586	0 140–1 032	0 223	9	[illegible]
(b) Submandibular saliva	0 268	0.102–0 434	0 083	9	
(c) Total saliva	0 60	(0 20–1 07)	–	9	
Urea (mg/l)					
Parotid saliva	252	–	–	41	The urea content of saliva is usually 75–90% of the content in the blood
Total saliva	200	(140–750)	–	4	
Creatinine (mg/l)	–	(5–20)	–	4	Values depend on the method used[71]
Ammonia (mg/l)	60	(10–120)	–	6	Values from stimulated saliva The wide fluctuation in the ammonia conten is partly explained by the instability of urea
Amino acids					[illegible]
Choline (mg/l)	–	(5–36)	–	49	Measured on stimulated saliva in 2 subjects Phosphoethanolamine has als been found in parotid and submandibular saliva[21]
Uric acid (mg/l)	15	(5–29)	–	8	The uric acid content is higher in stimulated saliva
Histamine (mg/l)	0 15	(0 11–0 18)	–	50	Measured in 48 samples from 24 healthy subjects There are no considerabl fluctuations during the course of the day
Proteins (g/l)					
(a) Parotid saliva	2 62	0–5 38	1.38	51	(a) Values from 25 subjects by the biuret reaction, (b) range of values in th literature The salivary proteins consist mainly of mucins, plasma proteins an enzymes, they arise in part from bacteria, epithelial cells and leucocytes Th protein content of parotid saliva is constant at rates of secretion exceedin 0 1 ml/min but reduced at lower rates of secretion[36] Various plasma protein have been detected in saliva by the immunoelectrophoretic technique[52–57] an include albumin, haptoglobin, transferrin, orosomucoid, γA globulin and en zymes
(b) Total saliva	–	(1 4–6 4)	–	4	
Mucins (g/l)	2 7	(0 8–6 0)	–	8	[illegible]
Parotid saliva (mg/l)					
Hexosamine, bound	99	(20–223)	59	60	Measured on 26 subjects, aged 5–18 years
Fucose, bound	89	(33–244)	54	60	
Hexose, bound	195	(73–441)	100	60	
Sialic acid, bound	12.4	(3 5–21 1)	8 1	60	
Enzymes					Enzymes should be looked for only in clean catheterized saliva since the tot [illegible]
Lysozyme (g/l)	–	up to 0 15	–		

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Amylase (ptyalin) (mg/ml)					
Parotid saliva	1.03	–	0.44	65	Values from 16 subjects. The amylase of saliva is an α-amylase; in paroti it is the main protein component[3]. The amylase content depends on the of the stimulant[2,66]. It is low in the newborn and reaches the adult v: wards the end of the first year of life[3].
Submandibular saliva	0.25	–	0.24	65	
Sublingual saliva	0.26	–	0.32	65	
Total saliva	0.38	–	0.32	65	
Nitrogen-free substances					
Reducing substances (glucose) (mg/l)					
(a) Parotid saliva	11.4	–	–	41	(a) Measured by the HAGEDORN-JENSEN method; (b) values from 39 su by the glucose oxidase method, (c) usual values in the literature bas reduction methods; values depend on the method used[68]. Sex difference: not been observed; the glucose content of saliva is slightly increased i age[67]. In addition to glucose, saliva contains maltose, arabinose and ribc
(b) Total saliva	26	2–50	12	67	
(c) Total saliva	–	(100–300)	–	4	
Citric acid (mg/l)	–	(up to 20)	–	4	Values from a variety of stimulated samples. When samples are allow stand for long the citric acid is broken down by bacteria.
Lactic acid (mg/l)	–	(10–50)	–	6	Values from stimulated saliva. The lactic acid content rises steeply after r Most of the lactic acid is a breakdown product of carbohydrates and m due to bacterial action.
Cholesterol (mg/l)	–	(25–500)	–	4	Cholesterol has been found in parotid and submandibular saliva[9].
Vitamins					
Folic acid (µg/l)	41	(2–165)	–	69	Determined with *Lactobacillus casei* in 24 subjects.
Ascorbic acid (mg/l)	2.18	0.58–3.78	0.80	70	Values from 31 healthy subjects. No connection has been demonstrated tween caries and the ascorbic acid content of the saliva.

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(For references see pages 650–651)

ing to the difficulty of collecting pure gastric juice the exact osition of this body fluid is not known for certain. The use gastric tube or even a gastric fistula yields not pure gastric but simply the gastric contents, almost always containing , food remnants and occasionally also bile, pancreatic juice ntestinal contents Unless otherwise stated, the following s apply to unstimulated gastric juice obtained from fasting cts by means of permanent intubation

The gastric juice can be roughly divided into two compo-, that of the parietal cells (parietal secretion) and that of the other cells (nonparietal secretion)[1, 2]. Both these components are roughly isotonic with the serum. The volumes of the two components are related as follows:

$$V_P = V_{total}\,(0\ 219 + 4\ 88\ A)$$
$$V_{NP} = V_{total} - V_P$$

(V_{total} = total secretion [ml]; V_P = parietal secretion [ml], V_{NP} = nonparietal secretion [ml], A = acidity [mEq/ml])

The composition of the gastric juice thus depends on the proportions of the individual cellular secretions, the amounts and compositions of which are in turn dependent on the nature of the stimulus. There is a considerable literature on the composition of the gastric juice[2-6], on the diagnostic aspects of gastric juice analysis see the literature[7, 8].

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
sicochemical data					
ing volume (ml)					
Newborn	2 65	(0 4–12 3)	2 05	9	
Infants	2.4	(1.0–3 5)	0 7	10	
Children	8 8	(0 4–[80])	8 2	10	
Adults	50	(0–180)	–	8	
earance					
retion rate (ml/h)					
Infants	18 6	(6–54)	18	10	
Young children					
Fasting (basal)	31	(10–64)	–	27	
After histamine (maximal)	52	(28–105)	–	27	
~~Children~~	~~50 4~~	~~(6–180)~~	~~25 2~~	~~10~~	
Adults					
Fasting (basal)	74	(0–176)	–	8	
At night	46	(12–99)	–	8	
After meals	101	(13–217)	–	8	
After histamine	117	(2–256)	–	8	
After insulin	124	(70–204)	–	8	
ecific gravity	–	*(1 004–1 010)*	–	8	
eezing-point depression (°C)	0 47	(0 30–0 82)	–	8	
ater (g/l)	–	(994–995)	–	3	
ry substance (g/l)	5 6	–	–	3	
H value					
a) Newborn	2 52	(1 2–7 4)	1 53	9	
b) Children	3 27	(0 9–7 7)	2 01	10	
c) Men	1 92	–	1 28	11	
d) Women	2.59	–	2 08	11	

Gastric Juice

(For references see pages 650–651)

	Mean	Extreme range	s	Reference	Remarks
Acidity					
Total acid (mEq/l)					
(b) Children	38.2	(4–126)	21.6	10	Values from (a) 154 newborn children, (b) 695 samples from 59 (mean age 9 years), (c) 15 men and 4 women (aged 20–25), (d) 10 (mean age 21 months). The acid secreted by the parietal cells consists e: of hydrochloric acid, which is partly neutralized, buffered and dilut secretion of the other cells. The total acid corresponds to a titration (of pH 7–8, the free acid to one of pH 2.5–3.5. The difference betweer and free acid is known as bound acid and corresponds roughly to th(part of the hydrochloric acid; whether this distinction is a valid one, is doubtful. The present preferred method is to titrate the acid to tl point using phenol red or the electrometric technique up to pH 7.4[2·] earlier 'clinical unit' was mEq acid per litre, corresponding to mi 0.1-NaOH per 100 ml.
(c) Adults	–	(5–118)	–	14	
Free acid (mEq/l)					
(a) Newborn	21.4	–	11.7	9	
(b) Children	28.1	(0–100)	17.9	10	
(c) Adults	–	(0–115)	–	14	
Free acid (mEq/h)					
(d) Young children					
Fasting (basal)	0.48	(0.00–1.32)	–	27	
After histamine (maximal)	2.59	(0.80–3.73)	–	27	
(e) Men					
Fasting (basal)	2.4	–	–	8	
At night	1.7	–	–	8	
After betazol (submaximal)	11.6	–	–	8	
After histamine (submaximal)	11.8	–	–	8	
After histamine (maximal)	22.4	–	–	8	
After insulin	16.5	–	–	8	

Gastric juice secretion under maximal histamine stimulation (augmented histamine test). The acid secretion is determined both under basal conditions and following a subcutaneous dose of 0.04 mg histamine monophosphate per kilogramme body weight[22, 23, 69]. The following are measured (all in mEq acid per unit of time):

- one-hour morning basal acid output (MBAO or BAO) = acid secretion during one hour in the morning without stimulation
- maximum acid output (MAO) or maximal secretory response (MSR) = acid secretion during one hour after maximum stimulation with histamine
- maximal histamine response (MHR) = acid secretion during the second and third quarter-hours after maximum stimulation with histamine
- peak acid output (PAO) = 2 × MHR

The acid secretion can also be stimulated[29] by betazol given subcutaneously (values for submaximal stimulation are given in the table below), by histamine given by the continuous intravenous route, by insulin or 2-deoxy-D-glucose (under vagus stimulation), or by gastrin or another synthetic pentapeptide of this type.

The acidity of both unstimulated and stimulated gastric juice varies and sex (see the tables below). The basal acid secretion varies with th day and is least at about 2 a.m.[17]. The highest acidity values found in around 150 mEq/l[21]. At birth the acid content of the gastric juice is but rises to the value given in the table during the first hours of life[19] dren there is good correlation between the acid secretion under histam ulation and body weight (about 2 mEq/h per 10 kg body weight)[27] maximum acid output is largely constant in any one individual and pr measure of the total parietal cell mass[30]; about 40 million parietal cell essary to produce 1 mEq of hydrochloric acid per hour under maximur lation.

There has been much discussion of the usefulness of the acid secreti for the diagnosis of gastric and intestinal ulcers[25, 31]. If the basal aci exceeds 60% of the maximum acid output the patient is almost (suffering from the ZOLLINGER-ELLISON syndrome[22]. Anacidity (pH der maximum stimulation with histamine is rare[32] and seen only i atrophy of the gastric mucosa, as for instance in pernicious anaemia.

Acid secretion in adults before and after maximum histamine stimulation (subcutaneous dose of 0.04 mg histamine monophosphate per kilogramme body weight)

	Number of subjects	Volume (ml/h) mean	Volume (ml/h) s	Total acid (mEq/h) mean	Total acid (mEq/h) s	Free acid (mEq/h) mean	Free acid (mEq/h) s
			From DOTEVALL[11]				
Basal secretion							
Men	30	64.0	21.4	3.70*	2.12	2.59	1.97
Women	12	54.2	24.2	2.24*	1.76	1.48	1.33
After histamine							
Men	24	201.6	53.4	23.3**	6.9	20.5	6.8
Women	12	153.7	33.3	17.7**	5.4	15.7	5.1
			From BARON[69]				
Basal secretion							
Men	20	38.7	23.01	1.3*	1.59	–	–
Women	20	40.6	38.8	1.1*	1.75	–	–
After histamine							
Men	20	177	73.3	17.1**	11.94	–	–
Women	20	107	57.7	9.4**	7.20	–	–

* Basal acid output (BAO). ** Maximal acid output (MAO).

Acid secretion in adults before and after betazol stimulation[70] (su neous dose of 0.5 mg betazol hydrochloride per kilogramm weight)

Age	Men Number	Men Free acid (mEq/h) Extreme range	Men Free acid (mEq/h) Mean	Men Free acid (mEq/h) s	Women Number	Women Free acid (mE Extreme range	Women Free acid (mE Mean
			Basal secretion				
20–29	74	0–17.1	2.50	2.81	65	0– 8.6	1.74
30–39	157	0–14.9	2.63	2.70	145	0–15.0	1.58
40–49	156	0–12.3	2.83	3.01	184	0–13.5	1.43
50–59	158	0–17.0	2.25	3.04	162	0– 6.7	0.98
> 60	70	0– 9.9	1.48	2.18	78	0– 7.6	0.95
All ages	615	0–17.1	2.44	2.85	634	0–15.0	1.33
			After betazol				
20–29	74	0–29.6	11.46	6.69	65	0.3–20.8	7.79
30–39	157	0–31.3	12.83	6.69	145	0–22.1	7.83
40–49	156	0–48.4	13.29	8.66	184	0–24.7	8.12
50–59	158	0–31.5	10.67	7.11	162	0–22.8	6.90
> 60	70	0–24.8	7.67	7.56	78	0–20.0	6.67
All ages	615	0–48.4	11.64	7.62	634	0–24.7	7.53

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
anic substances					
bonate	...	...	...	...	The secretion of the covering cells is reported to contain 45 mEq bi per litre[17]
ide (mEq/l)..........	–	(77.6–159)	–	14	The chloride content of the parietal secretion is about 170 mEq/l, t nonparietal secretion about 125 mEq/l[2,17]. Values below 130 mEq/ contamination of the gastric juice by saliva and intestinal contents[2]
phorus (mg/l)	70	([6]–[180])	–	33	
iide (mg/l)	–	(0 6–9.0)	–	34	
ride (mg/l)	–	(0.4–0.7)	–	35	
cyanate ..	...			..	The presence of thiocyanate in the gastric juice indicates probable c tion with saliva[36]
ssium (mEq/l) ..	11 6	(6 4–16 6)	–	37	Values from 50 men. Potassium is secreted in about the same concen the parietal cells as by the other cells Changes in the potassium con histamine stimulation are variable[38] High values indicate contamin saliva
um (mEq/l)	49	(18 7–69.5)	–	37	
ium (mEq/l)	3 6	(2.0–4 8)	–	37	Values from 50 men. The calcium is found in the parietal secre calcium values indicate contamination by saliva
nesium (mEq/l)	1.5	(0 3–3 0)	–	39	Values from 43 subjects
per (mg/l)	–	(0 1–0 4)	–	40	Values from 7 subjects
anic substances					
al nitrogen (mg/l)					
	752	–	–	41	Values from (a) 21 patients with healthy stomachs, (b) 6 young me
	–	(910–2180)	–	14	
nprotein nitrogen (mg/l)					
	415	–	–	41	Values from (a) 21 patients with healthy stomachs, (b) 10 subjects protein nitrogen represents about 20–80% of the total nitroge subjects with healthy stomachs and patients with gastric complaint
	–	(150–320)	–	42	
nide nitrogen (mg/l)	–	(38–70)	–	42	Values from 10 subjects
ino-acid nitrogen (mg/l)	–	(16–75)	–	42	Values from 10 subjects
e amino acids (mg/l)	316	–	–	43	Values from 15 subjects, 18 amino acids were determined Hyperac juice has an increased content of free amino acids For a review se ture[44]
amonia (mg/l)	97	67–127	15	45	Values from 24 subjects The ammonia content is increased in ura liver cirrhosis[46].
ea (mg/l) ..	84	–	15	45	Values from 24 subjects The urea content is increased in uraemia
eatinine (mg/l)	–	(12–33)	–	8	
ic acid (mg/l) ...	–	(8–69)	–	42	

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Histamine (µg/l)	–	(7–48)	–	47	
Proteins (g/l)	2.8	2.2–3.4	0.3	48	Determined by the biuret reaction; values in agreement with those obta other methods[36,49,50]. The proteins of gastric juice are a very heterogeneous mixture[52,53] and mucins rich in carbohydrate, enzymes and plasma proteins (albumin, γ bulin, γA-globulin and others[54]). At low pH values they are readily down by enzymes into peptides and amino acids. Increased album ues occur often in cancer of the stomach, in atrophic gastritis and al MÉNÉTRIER's disease[52,55]. On the rate of flow of plasma into the stom WETTERFORS[55].
Albumin (g/24 h)	–	(0.02–0.69)	–	51	
γ-Globulin (g/24 h)	–	(0.03–0.38)	–	51	
Mucins (g/l)	–	(0.6–15.0)	–	5	The mucins are contained in the covering-cell secretion (visible muc are also secreted by the other cells of the glands except the parietal cells dular mucoproteins, mucoproteoses). The mucous substances are cher very heterogeneous[52,53,56,57] and consist mainly of mucoproteins sialic acid and mucopolysaccharides rich in fucose (including the blood-specific substances). The intrinsic factor (see page 484) and various v B_{12}-binding substances are also mucoproteins. Determination of the in factor secretion is a diagnostic aid in pernicious anaemia[58].
Undissolved substances	1.4	–	–	56	
Trichloracetic acid precipitate	1.0	–	–	56	
Mucoproteins	0.5	–	–	56	
Mucoproteoses	1.2	–	–	56	
Carbohydrates, bound (mg/l)					
(a) Hexoses	321	–	–	50	Values from (a) 16, (b) 10, (c) 15, (d) 13 and (e) 12 subjects. The carboh are components of the mucoproteins and mucopolysaccharides. Their bution has been studied by electrophoretic separation of the protein fractic An increase in the carbohydrate content of the gastric juice has been obs in cancer of the stomach and pernicious anaemia[50].
(b) Hexosamines	327	–	–	50	
(c) Fucose	138	–	–	50	
(d) Sialic acid	73	–	–	50	
(e) Glucuronic acid	20	–	–	50	
Lactic acid	...	...	...	...	Lactic acid arises from the carbohydrates by bacterial action, but only i acidic and hypoacidic gastric juice.
Lipids	...	...	...	...	The gastric juice appears to contain small amounts of lipids[60] but these not been further investigated.
Enzymes	...	...	...	...	The gastric juice contains mainly protein-splitting enzymes[52]. Other enz present are lipase[61], lysozyme[62], lactate dehydrogenase[63,64], isocitrat hydrogenase[64], aminotransferases[64], fructosediphosphate aldolase[64], alk phosphatase[64], leucine aminopeptidase[64], oxoglutarate dehydrogenase[64], cosephosphate isomerase[64], β-glucuronidase[64] and ribonuclease[64]; the ase[46] is probably of bacterial origin. The lactate dehydrogenase and β curonidase contents are increased in cancer of the stomach.
Pepsin (kU/24 h, 37 °C)					
Men	28.8	–	13.5	65	Values from 10 men and 10 women (for definition of the unit U see page The gastric juice in man contains at least 3 protein-splitting enzymes namely 2 pepsins and a protease with a maximum activity at pH 7. Accor to TAYLOR[66] one pepsin is secreted by the chief cells of the fundus glands other by the pylorus glands. According to TANG and WOLF[67] the proteo activity at pH 2 is due to the pepsins, that at pH 3.5 to gastricsin. The pe content of the gastric juice is greatly reduced after histamine stimulation greatly increased after vagus stimulation; it is decreased in cancer of stomach and atrophy of the gastric mucosa[12,66].
Women	18.9	–	7.5	65	
Vitamins					
Vitamin B_{12} (µg/l)	–	(0.06–3.0)	–	68	
Ascorbic acid (mg/l)	–	(1.5–15.0)	–	5	

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Pancreatic Juice

(For references see page 653)

The pancreatic juice probably arises from two different types of ells the one type, presumably the epithelial cells of the ducts, ecrete a very watery juice rich in bicarbonate, whereas the other ype, the epithelial cells of the acini, produce a viscous secretion ich in enzymes Various stimuli, for instance acids, bring about he liberation of secretin and pancreozymin from the duodenal mucosa Secretin stimulates mainly the secretion of fluid and bicarbonate, while pancreozymin, acetylcholine and vagus stimulation cause an increase in the liberation of enzymes. Unless otherwise stated, the data given in the table below apply to unstimulated pancreatic juice obtained either by means of intubation (here designated duodenal contents) or an external pancreatic fistula For further data on the pancreatic juice see the literature[1-3]

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Physicochemical data					
Appearance					Watery, colourless, thin fluid, clear or slightly opalescent Because of its similarity to saliva, the pancreatic juice is also known as abdominal saliva
Secretion rate (ml/h)					
Young children	–	(4–13)	–	4	—
Adults	36	(>0–99)	–	2	
Secretin test[8-9]					
(ml/h)	176	38–314	69	8	Valu
(ml/h/kg body weight)	2.68	1 04–4 32	0 82	9	
Specific gravity	–	(1 008–1 011)	–	11–13	
Freezing-point depression (°C)	–	(0 55–0 63)	–	12 13	The
Water (g/l)	987	–	–	11	
Dry substance (g/l)	13 0	(7 5–15 7)	–	14	Valu tion
pH value	–	(7.5–8 8)	–	15 16	

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
norganic substances					
Bicarbonate (mEq/l)	–	(25–[150])	–	17	The bicarbonate content of pancreatic juice rises in the form of a hyperbol curve from 25 mEq/l at a secretory rate of 40 ml/h up to 130–150 mEq/l at secretory rate of 300 ml/h. The sum of the bicarbonate and chloride concentr tions is constant and amounts to about 154 mEq/kg water[17].
Secretin test[1-5]					
(mEq/h)	13.5	0–27.1	6.8	9	Values from 47 adults with a healthy pancreas, obtained by analysing t pancreatic juice during the hour following intravenous injection of 2 units secretin per kilogramme body weight. The results of the test in adults a almost independent of sex and age[10]. The bicarbonate concentration is d creased in chronic pancreatitis.
(mEq/h/kg body weight)	0.199	0.047–0.351	0.076	9	
(mEq/l)	76	62–90	7	9	
Chloride (mEq/l)	–	([4]–129)	–	17	The chloride content of pancreatic juice is determined by the bicarbona content (see under 'Bicarbonate' above). With increasing secretory rate th chloride content falls in the form of a hyperbolic curve.
Phosphate (mmol/kg water)	0.8	0–1.6	0.4	17	From analysis of the duodenal contents. The values accord with those fo fistular juice[16].
Potassium (mEq/l)					In (a) duodenal contents, (b) fistular juice.
(a)	–	(6–9)	–	17	
(b)	–	(4.1–5.5)	–	16	
Sodium (mEq/l)	–	(139–143)	–	17	From analysis of the duodenal contents; in agreement with values from th fistular juice of 3 subjects[15]. The sodium content of the pancreatic juice largel parallels that of the serum.
Calcium (mEq/kg water)	3.4	2.2–4.6	0.6	17	From analysis of the duodenal contents; in agreement with values from th fistular juice of 3 subjects[15].
Magnesium (mEq/kg water)	1.0	–	–	17	From analysis of the duodenal contents.
Other minerals	...	...	...	...	The following have also been found in the fistular juice[1]: sulphur (but nc sulphate[15]), silicic acid, zinc (a component of carboxypeptidase A) and traces of copper.
Organic substances					
Total nitrogen (g/l)	–	(0.76–0.98)	–	1	Results of analyses of fistular juice made during the period 1902–1912.
Nonprotein nitrogen (g/l)	0.14	–	–	15	From the fistular juice in 3 subjects.
Proteins (g/l)					Values from (a) duodenal contents of 3 subjects, (b) fistular juice of 3 subjects. The greater part of the proteins in pancreatic juice are enzymes and their pre-cursors, the remainder plasma- and mucoproteins. Electrophoretic separation has yielded up to 7 fractions[14].
(a)	–	(4.8–5.3)	–	18	
(b)	–	(1.9–3.4)	–	15	
(b) Albumin	0.6	–	–	15	
(b) Globulin	0.4	–	–	15	
Urea (mg/l)	107	–	–	15	From the fistular juice in 3 subjects.
Creatinine	trace	–	–	16	
Uric acid (mg/l)	2	–	–	15	
Reducing substances (as glucose) (mg/l)	–	(85–180)	–	16	From the fistular juice in 1 subject
Lipids (mg/l)	5.2	–	–	2	Cholesterol has not been found in the fistular juice[15].
Enzymes	...	...	...	...	Pancreatic juice is rich in enzymes and their precursors. The principal en-zymes are the zymogens of proteases and peptidases such as trypsinogen, chymotrypsinogen and procarboxypeptidases, small amounts of amylase, lipase, phospholipase, ribonuclease, deoxyribonuclease, clostridiopeptidase A and pancreatopeptidase E are also present[19]. The fistular juice contains pro-teolytic enzymes[20] as well as amylase and lipase[14,21]. The presence of a trypsin inhibitor in the pancreatic juice has also been reported[22]. The pan-creatic juice is often free of enzymes, and their absence is not a specific feature of cystic fibrosis[4,23]. The enzyme content is increased after injection of acetylcholine or pancreozymin and after vagus stimulation.
By pancreozymin test[7,8,24,25]:					
Amylase (mg/min)	0.62	0.29–1.30	–	25	See remarks under 'Chymotrypsin', 'Trypsin' and 'Lipase' opposite.
Carboxypeptidase A (mg/min)	0.72	0.36–1.45	–	25	

Pancreatic Juice

(For references see page 653)

The pancreatic juice probably arises from two different types of ells the one type, presumably the epithelial cells of the ducts, ecrete a very watery juice rich in bicarbonate, whereas the other ype, the epithelial cells of the acini, produce a viscous secretion ich in enzymes Various stimuli, for instance acids, bring about he liberation of secretin and pancreozymin from the duodenal nucosa. Secretin stimulates mainly the secretion of fluid and bicarbonate, while pancreozymin, acetylcholine and vagus sti cause an increase in the liberation of enzymes Unless c stated, the data given in the table below apply to unstimul creatic juice obtained either by means of intubation (here d duodenal contents) or an external pancreatic fistula For fu on the pancreatic juice see the literature[1–3].

	Mean	95% range (*extreme range in brackets*)	*s*	Reference	*Remarks*
Physicochemical data					
Appearance					Watery, colourless, thin fluid, clear or slightly opalescent Because larity to saliva, the pancreatic juice is also known as abdominal sali
Secretion rate (ml/h)					
Young children	–	(4–13)	–	4	
Adults	36	(>0–99)	–	2	
Secretin test[5–8]					
(ml/h)	176	38–314	69	9	
(ml/h/kg body weight)	2 68	1 04–4 32	0 82	9	
Specific gravity	–	(1 008–1.011)	–	11–13	
Freezing-point depression (°C)	–	(0 55–0 63)	–	12 13	The pancreatic juice is roughly isotonic with the serum.
Water (g/l)	987	–	–	11	
Dry substance (g/l)	13 0	(7.5–15 7)	–	14	Values from fistular juice in 2 subjects About 50–60% of the dry inorganic
pH value	–	(7.5–8 8)	–	15 16	

	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks
Inorganic substances					
Bicarbonate (mEq/l)	–	(25–[150])	–	17	The bicarbonate content of pancreatic juice rises in the form of a hyp curve from 25 mEq/l at a secretory rate of 40 ml/h up to 130–150 mE secretory rate of 300 ml/h. The sum of the bicarbonate and chloride con tions is constant and amounts to about 154 mEq/kg water[17].
Secretin test[6–9]					
(mEq/h)	13.5	0–27.1	6.8	9	Values from 47 adults with a healthy pancreas, obtained by analysi pancreatic juice during the hour following intravenous injection of 2 u secretin per kilogramme body weight. The results of the test in adu almost independent of sex and age[10]. The bicarbonate concentration creased in chronic pancreatitis.
(mEq/h/kg body weight)	0.199	0.047–0.351	0.076	9	
(mEq/l)	76	62–90	7	9	
Chloride (mEq/l)	–	([4]–129)	–	17	The chloride content of pancreatic juice is determined by the bicarl content (see under 'Bicarbonate' above). With increasing secretory ra chloride content falls in the form of a hyperbolic curve.
Phosphate (mmol/kg water)	0.8	0–1.6	0.4	17	From analysis of the duodenal contents. The values accord with the fistular juice[16].
Potassium (mEq/l)					
(a)	–	(6–9)	–	17	In (a) duodenal contents, (b) fistular juice.
(b)	–	(4.1–5.5)	–	16	
Sodium (mEq/l)	–	(139–143)	–	17	From analysis of the duodenal contents; in agreement with values fro fistular juice of 3 subjects[15]. The sodium content of the pancreatic juice l parallels that of the serum.
Calcium (mEq/kg water)	3.4	2.2–4.6	0.6	17	From analysis of the duodenal contents; in agreement with values fro fistular juice of 3 subjects[15].
Magnesium (mEq/kg water)	1.0	–	–	17	From analysis of the duodenal contents.
Other minerals	...	...	...	...	The following have also been found in the fistular juice[1]: sulphur (b sulphate[15]), silicic acid, zinc (a component of carboxypeptidase A) and of copper.
Organic substances					
Total nitrogen (g/l)	–	(0.76–0.98)	–	1	Results of analyses of fistular juice made during the period 1902–1912.
Nonprotein nitrogen (g/l)	0.14	–	–	15	From the fistular juice in 3 subjects.
Proteins (g/l)					
(a)	–	(4.8–5.3)	–	18	Values from (a) duodenal contents of 3 subjects, (b) fistular juice of 3 sub The greater part of the proteins in pancreatic juice are enzymes and thei cursors, the remainder plasma- and mucoproteins. Electrophoretic separ has yielded up to 7 fractions[14].
(b)	–	(1.9–3.4)	–	15	
(b) Albumin	0.6	–	–	15	
(b) Globulin	0.4	–	–	15	
Urea (mg/l)	107	–	–	15	From the fistular juice in 3 subjects.
Creatinine	trace	–	–	16	
Uric acid (mg/l)	2	–	–	15	
Reducing substances (as glucose) (mg/l)	–	(85–180)	–	16	From the fistular juice in 1 subject.
Lipids (mg/l)	5.2	–	–	2	Cholesterol has not been found in the fistular juice[15].
Enzymes	...	...	...	...	Pancreatic juice is rich in enzymes and their precursors. The princip zymes are the zymogens of proteases and peptidases such as trypsino chymotrypsinogen and procarboxypeptidases; small amounts of amy lipase, phospholipase, ribonuclease, deoxyribonuclease, clostridiopeptida and pancreatopeptidase E are also present[19]. The fistular juice contains teolytic enzymes[20] as well as amylase and lipase[14,21]. The presence trypsin inhibitor in the pancreatic juice has also been reported[22]. The creatic juice is often free of enzymes, and their absence is not a specific fea of cystic fibrosis[4,23]. The enzyme content is increased after injectio acetylcholine or pancreozymin and after vagus stimulation.
By pancreozymin test[7,8,24,25]:					
Amylase (mg/min)	0.62	0.29–1.30	–	25	See remarks under 'Chymotrypsin', 'Trypsin' and 'Lipase' opposite.
Carboxypeptidase A (mg/min)	0.72	0.36–1.45	–	25	

Bile

(For references see page 656)

	Hepatic bile				Gallbladder bile				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Dry substance (g/l)	20	(8–34)	9	6	136	(70–248)	60	6	About 85–95% of the dry substance is organic. Water and salts are absorbed in the gallbladder, so that the increase of concentration of the gallbladder bile involves mainly the organic constituents; concentration is also aided by the release of mucopolysaccharides from the gallbladder epithelium.
	–	(23–33)	–	7	180	–	–	7	
	33.9	28.9–38.9	2.5	8	166	(144–219)	–	9	
pH value	7.15	–	–	10	6.89	–	–	10	Gallbladder bile is rather more acid than hepatic bile, possibly as a result of the enzymatic formation of lactic acid in the gallbladder.
	7.5	(6.2–8.5)	–	11	6.0	(5.6–8.0)	–	11	
Inorganic substances									
Bicarbonate (mEq/l)	30	–	–	10	19	–	–	10	Like the bicarbonate content of the pancreatic juice, that of the bile increases as the rate of secretion increases[3].
Chloride (mEq/l)	100.6	(89–118)	–	12	31	(7–110)	–	13	
Total phosphorus (g/l)	0.148	0.060–0.236	0.044	7	1.40	–	–	7	Most of the phosphorus is contained in phospholipids.
Potassium (mEq/l)	4.98	(2.6–12.0)	–	12	13.5	(8.4–17.5)	–	13	
Sodium (mEq/l)	148.9	(131–164)	–	12	220	(146–360)	–	13	
Calcium (mEq/l)	–	(3.3–4.1)	–	14	15.4	(3.9–33.2)	–	13	
Magnesium	...	...	...	...	...	...	...	...	The magnesium content of the bile is roughly the same as that of the serum[15].
Iron (mg/l)	–	(0.4–3.1)	–	1	–	(0.6–3.8)	–	1	
Copper (mg/l)	–	(0.35–2.05)	–	16					
Other minerals	...	...	...	...	...	...	...	...	The bile contains small amounts of zinc and manganese.
Organic substances									
Total nitrogen (g/l)	0.72	(0.24–1.45)	0.31	6	3.49	(1.88–6.00)	1.45	6	The total nitrogen of gallbladder bile fluctuates widely because of the variable bilirubin and protein content. About 40% of the nitrogen of gallbladder bile is dialysable[18].
	0.77	(0.68–0.92)	–	7	4.9	–	–	7	
					2.8	(1.6–3.3)	–	17	
Nonprotein nitrogen (g/l)	0.46	–	–	19	–	(0.68–0.94)	–	19	Most of the nonprotein nitrogen is due to bilirubin, choline (component of the phospholipids), urea and amino acids (mainly glycine and taurine as components of the bile-acid conjugates).
					2.7	–	–	17	
Peptide nitrogen (mg/l)	140	–	–	19	–	(39–270)	–	19	
Amino-acid nitrogen (mg/l)	54	–	–	19	–	(60–216)	–	19	
Urea (mg/l)	236	–	–	19	–	(200–450)	–	19	
Choline (g/l)	0.57	0.22–0.92 (0.35–0.89)	0.175	7	5.5	–	–	7	Choline is contained in the phospholipids.
Bilirubin (g/l)	0.65	(0.12–1.35)	0.13	6	2.94	(0.36–6.30)	1.94	6	Free bilirubin does not occur in the bile; 70–80% of the bilirubin of gallbladder bile and over 90% of that of hepatic bile occur as bilirubin diglucuronide, the remainder as bilirubin monoglucuronide[20]. Apart from bilirubin, bile contains also small amounts of other bile pigments[1,21]. The bilirubin content of gallbladder bile is decreased in cirrhosis of the liver[22].
	–	(0.26–0.41)	–	7					
Porphyrins (µg/l)	...	...	...	...	101	–	–	23	The porphyrins consist of coproporphyrin I and III[1].

	Hepatic bile				Gallbladder bile				Remarks
	Mean	95% range (extreme range in brackets)	s	Reference	Mean	95% range (extreme range in brackets)	s	Reference	
Proteins (g/l)	1.8	(1 4–2 7)	–	7	4.5	–	–	7	The bile proteins consist of plasma proteins, mucopolysaccharides and enzymes The presence of various plasma proteins has been demonstrated immunologically [17 24], *namely albumin*, orosomucoid, α_2-haptoglobin, transferrin and γG-globulin, as well as others specific to bile[25] The albumin fraction of hepatic bile is diminished in acute icterogenic hepatitis, while the other protein fractions are increased[26].
Enzymes	...	...		...		. .	...	...	The bile contains many enzymes[10 27,28], including esterases, phospholipase A, lipase, amylase, lactate dehydrogenase, malate dehydrogenase, transaminases, alkaline phosphatase, acid phosphatase, leucine aminopeptidase, L iditol dehydrogenase, glucose 6 phosphate dehydrogenase, creatine kinase, and fructosediphosphate aldolase The concentration of many of these enzymes in gallbladder bile is about 10 times their concentration in the serum[27].
Total carbohydrates (g/l)	–	(0.35–0 91)	–	7	2 4	–	–	7	The carbohydrates in hepatic bile mainly consist of glycoproteins[8] (see also under 'Proteins', above), those in gallbladder bile of mucopolysaccharides[18 28] These mu*copolysaccharides form a complex with the* lipids and bilirubin[18 29] Also found in gallbladder bile are galactose, glucose, small amounts of arabinose, fucose and ribose, glucosamine, galactosamine and uronic acids[18] The carbohydrate content of gallbladder bile is markedly lower in the presence of stone[18]
Hexosamine, bound (mg/l)	57	(5–160)	49	6	83	(30–180)	53	6	
Reducing substances (as glucose) (g/l)	–	(0 17–0.52)	–	7	0 8	–	–	7	*The reducing substances probably* consist mainly of glucose[18]
Lactic acid (mg/l)					–	(130–480)	–	30	
Lipids									In addition *to bile acids the main lipids of* bile are lecithin and cholesterol, also present are triglycerides, diglycerides and non esterified fatty acids[31 32]
Total fatty acids (g/l)	2 7	(1 6–4 1)	–	7	24	–	–	7	About 80% of the *fatty* acids consist of palmitic, oleic and linoleic acids[33] Non-esterified fatty acids make up only about 0 3% of the total lipids[32]
Phospholipids (g/l)	–	(1 0–4 3)	–	7	34	(15–53)	–	34	Lecithin accounts for about 98% of the phospholipids, the remainder consisting of cephalins and lysolecithins[31] In acute icterogenic hepatitis the phospholipid content of the bile is reduced[26]
Cholesterol (g/l)									
Children	–	(0 20–0 22)	–	35	–	(0 78–0 81)	–	35	In gallbladder bile about 4% of the total cholesterol is esterified, the remainder free[32] In acute icterogenic hepatitis the cholesterol content of the bile is reduced[26]
Adults	–	(0 8–1 8)	–	7	6 3	(3 1–16 2)	–	34	
Bile acids (g/l)	–	(6 5–14)	–	7	115	–	–	7	For other values see page 656 The bile acids in bile are mostly conjugated with glycine and taurine, only a small proportion being in the free form[37] In bile the bile acids are present as the anions They include small quantities of trihydroxycoprostanic acid[38], which arises in the liver from cholesterol, the primary bile acids (cholic and chenodeoxycholic acids), which are likewise formed in the liver and the secondary bile acids (deoxycholic, lithocholic and ursodeoxycholic acids), which are formed in the intestine by bacterial action from the primary bile acids, are there absorbed and again excreted in the bile[39] Since bacteria are absent from the newborn intestine the bile of newborn in-
					32 1	0–65 9	16 9	36	

Bile acid content of the bile in children and adults

Age	Number of subjects	Bile acids (mEq/l)*		Ratio glycine : taurine		Ratio cholic acid : chenodeoxycholic acid : deoxycholic acid
		Mean	Range	Mean	Range	
Hepatic bile (A fraction)[42]						
1–4 days	13	10.7	4.6–26.7	0.47	0.21–0.86	2.5:1:–
5–7 days	17	11.3	2.0–29.2	0.95	0.34–2.30	2.5:1:–
7–12 months	8	8.8	2.2–19.7	2.4	1.4 –3.1	1.1:1:–
4–10 years	3	3.4	2.4– 5.2	1.7	1.3 –2.4	2.0:1:0.9
20 years	19	8.1	2.8–20.0	3.1	1.9 –5.0	1.2:1:0.6
Gallbladder bile[37]						
Over 20 years	4	121	31.5–222	3.0	1.0 –6.6	1.0:1:0.5

* 1 mEq corresponds to ca. 0.4 g free bile acids.

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Intestinal Juice

The composition of the secretions of the various parts of the healthy human gut is unknown since it is impossible to obtain pure samples. The composition of the intestinal contents, however, has been determined[1]. The main constituents of the intestinal juice, apart from electrolytes, are proteins[2] (albumin, γ-globulins, mucoproteins, enzymes) and lipids[2]. The rate of flow of plasma into the jejunum is about 0.20 ml/10 cm/h, or 0.036 ml/cm^2/24 h[3].

Electrolyte content of the intestinal secretion in dogs[4]

	Duodenum	Jejunum	Ileum	Colon		Duodenum	Jejunum	Ileum	Colon
Volume (ml/h)	6–38	4–88	11–42	1–10	Chloride (mEq/l)	103–139	141–155	68–88	60–88
pH	6.5–7.6	6.3–7.3	7.6	7.9–8.0	Potassium (mEq/l)	5–9	4–10	5	6–9
Carbon dioxide (mmol/l)	–	5–27	70–97	86–93	Sodium (mEq/l)	138–156	126–152	146–156	136–151
					Calcium (mEq/l)	–	2–3	5	4–5

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	Mean	95% range (*extreme range* in brackets)	*s*	Reference	*Remarks*
'hysicochemical data					
ıppearance	...	.	...	...	Meconium Soft, sticky, homogeneous mass, odourless and ***greenish brown*** to ***black*** in colour. Infants' stools *Golden yellow* (bilirubin) on breast milk, turning *green* (biliverdin)
Ɔdour ...					Typical odour is due to volatile degradation products of protein
Amount					
Meconium (g) ...	–	(70–90)	–	5	Values from (a) 44 children, (b) 24 male adults The amount excreted daily depends on the amount and nature of the diet infants on breast milk excrete less faeces (ca 15–25 g/24 h[5]) than those on cow's milk (ca 30–40 g/24 h[5]), for adults the daily amount after long fasting falls to 9 5–22 g, on a purely meat diet it is 54–64 g, on a purely vegetable diet ca 370 g, in disease daily amounts of 500–1200 g or more occur[8]
(a) Children's stools, 2 months–6 years (g/24 h)	–	(6 6–54 1)	–	6	
(b) Adult stools (g/24 h)	115 3	33.1–197.5	41.1	7	
Number of stools per day					
Children					
1 day	–	(3–4)	–	9	69% of 500 healthy newborn infants had their first stools within 12 hours, 94% within 24 hours[10]
1 week	–	(4–5)	–	9	
2 weeks	–	(3–4)	–	9	
3–6 weeks	–	(2–3)	–	9	
7–13 weeks	–	(1–2)	–	9	
Water					
(a) Meconium (g/kg)	774	712–836	31	11	Values from (a) 12, (b) 44, (c) 7 subjects
(b) Children's stools, 2 months–6 years (g/kg)	–	(623–857)	–	6	
(c) Adult stools					
(g/kg)	750	–	–	12	
(g/24 h)	111	–	–	12	
Dry substance					
Meconium (g/kg)	276	–	–	13	
(a) Children's stools, 2 months–6 years (g/24 h)	–	(2 0–12 9)	–	6	
(b) Adult stools (g/24 h)	34 0	1 6–66 4	16 2	7	stance
(c) Adult stools (g/24 h)	21	11–31	5	12	
Ash (% of dry substance)					
Meconium	4 0	–	–	13	
Adults	20	–	–	8	
Calorific value					
(kcal/g dry substance)	5 15	(4 21–5 99)	–	15	Value
(kcal/24 h)	139	< 213 (upper limit of normal)	–	15	utiliz
pH value					
Meconium	6 1	(5 7–6 4)	–	16	The r
Infants' stools, 6 days (on breast milk)	4 9	(4 6–5 2)	–	16	
Adult stools	7 15	5 85–8 45	0 65	17	

Faeces

(For references see page 660)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Ions					
(mEq/kg) (anions or cations in solution)	–	(180–220)	–	20	Among the cations in solution are the sodium, potassium and ammonium an part of the calcium and magnesium, among the anions organic acids, free fatt acids, bicarbonate, chloride and part of the phosphate[21–23].
Inorganic substances					
Bicarbonate (mEq/kg)	< 30	–	–	22	
Chloride (mEq/24 h)	–	(0.5–3.0)	–	24	With an average chloride intake of 50–150 mEq/24 h.
Phosphorus					
(a) Meconium (mmol/kg)	5.28	2.38–8.18	1.45	11	Values from (a) 12 infants, (b) persons with an average phosphorus intake o 25–50 mmol/24 h. Most of the phosphorus is present as calcium phosphate, small part as phosphate ion in solution[22, 23].
(b) Adult stools (mmol/24 h)	–	(10–25)	–	24	
Sulphate	0	–	–	22	
Fluoride (mg/24 h)	–	(0.5–2.2)	–	25	With an average fluorine intake of 1.5–4.7 mg/24 h.
Iodine (µg/24 h)	–	(10–57)	–	26	Values from 7 persons.
Potassium					
(a) Meconium (mEq/kg)	31.4	11.8–51.0	9.8	11	Values from (a) 12 infants, (b) persons with an average potassium intake of 50–75 mEq/24 h, (c) 7 adults.
(b) Adult stools (mEq/24 h)	–	(5–15)	–	24	
(c) Adult stools (mEq/24 h)	11.3	3.3–19.3	4	12	
Sodium					
(a) Meconium (mEq/kg)	136	90–182	23	11	Values from (a) 12 infants, (b) persons with an average sodium intake of 50–150 mEq/24 h, (c) 7 adults.
(b) Adult stools (mEq/24 h)	–	(0.5–5.0)	–	24	
(c) Adult stools (mEq/24 h)	6.5	0.5–12.5	3	12	
Calcium					
(a) Meconium (mEq/kg)	23.2	6.5–39.9	8.35	11	Values from (a) 12 infants, (b) persons with an average calcium intake of 25–75 mEq/24 h. In adult stools about 10 mEq/24 h is of endogenous origin (intestinal secretions)[27].
(b) Adult stools (mEq/24 h)	–	(15–65)	–	24	
Magnesium					
(a) Meconium (mEq/kg)	39.2	18.2–60.2	10.5	11	Values from (a) 12 infants, (b) persons with an average magnesium intake of 20–40 mEq/24 h.
(b) Adult stools (mEq/24 h)	–	(10–30)	–	24	
Iron					
(a) Meconium (mg/kg)	16.8	(12.0–27.1)	–	28	Values from (a) 6 infants, (b) persons with an average iron intake of 7 mg/24 h.
(b) Adult stools (mg/24 h)	–	(5.7–6.7)	–	29	
Copper					
Meconium (mg/kg)	17.0	(9.5–24.7)	–	28	Values from 6 infants.
Adult stools (mg/24 h)	1.96	0–4.62	1.33	30	
Zinc					
Meconium (mg/kg)	65.0	(38.8–117)	–	28	
Adult stools (mg/24 h)	–	(5.1–10.3)	–	31	
Cobalt (µg/24 h)	–	(0.19–1.21)	–	32	
Manganese (mg/24 h)	3.69	0–8.29	2.30	30	
Other elements	...	...	...	...	The amounts of aluminium, lead and tin are of the same order as those in the food[30]. On strontium excretion see Schmid and Zipf[33], on strontium in meconium see Widdowson[11].
Nitrogenous substances					
Nitrogen					
Meconium (g/kg)	19	–	–	13	Values from (a) 24, (b) 7 persons. The nitrogenous components are from mucus and epithelial cells of the intestinal wall and from digestive juices, bacteria and food. 17% of the nitrogen is in the bacterial fraction; about 47% of it is water-soluble[12]. During fasting about 0.25 g nitrogen per day is excreted in the stools[1]. The nitrogen content is *increased* in some types of diarrhoea, as well as in pancreatic disease and steatorrhoea.
Infants' stools (g/24 h)					
On breast milk	0.16	–	–	1	
On cow's milk	0.4	–	–	1	
Adult stools (g/24 h)					
(a)	1.8	–	0.2	7	
(b)	1.1	–	–	12	

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
roteins	...	...	...	...	The proteins consist mainly of undigested nutrient proteins and bacte proteins, with only a very small proportion of plasma proteins, most of wh [illegible] specific substances
Amino acids	...	...	...	...	In children's stools free amino acids represent only a small part of the to nitrogen[36].
Ammonia (mg/kg)	–	(251–884)	–	37	Ammonia arises in the terminal intestine from bacterial action
Porphyrins					
Coproporphyrin (mg/24 h)	0 422	0 012–0 832	0 205	38	Deutero- and mesoporphyrin are also present[38] The porphyrin content is ofi increased in idiopathic steatorrhoea[38] and some porphyrias[39]
Protoporphyrin (mg/24 h)	0 955	0–2 09	0 567	38	
Bilirubin					[illegible]
Meconium (mg/kg)	585	(252–1020)	–	40	
Adult stools (mg/24 h)	–	(5–20)	–	41	
Urobilinogen (mg/24 h)					
Men	101	(57–200)	–	43	As determined, 'urobilinogen' includes various colourless and coloured ba terial breakdown products of bilirubin (particularly stercobilinogen and ste cobilin) Urobilinogen is rarely found in the stools in the first week of life ai is present only in small and fluctuating quantity during the first year[41] C bilirubin breakdown see page 362
Women	40	(80–150)	–	43	
Purine bases					
As nitrogen (mg/24 h)	–	(63–73)	–	44	Uric acid is also present in small amount in the stools and meconium[f].
Enzymes					The enzymes arise from digestive secretions, cells of the intestinal wall ai bacteria
Trypsin (mg/g)	0 065	–	–	45	Meconium contains no trypsin[46] In chronic pancreatitis the trypsin ar chymotrypsin content of the stools is often lowered[45]
Chymotrypsin (mg/g)	0 421	–	–	45	
Non-nitrogenous substances					
Carbohydrates (g/kg)					
Children, up to 1 year	–	(< 8)	–	47	In the faeces of healthy adults these consist solely of indigestible polysacchi rides from food, such as cellulose and hemicellulose Mono- and disacchi rides are found occasionally in infants' stools, glucuronic acid in the stools c newborn
Adults	0	–	–	47	
Organic acids (mEq/kg)	150	(100–400)	–	22	Organic acids make up rather more than 50% of the anions of faeces and aris from bacterial decomposition of carbohydrates See also below under 'Volatil fatty acids' and 'Lactic acid'
Lactic acid (mg/24 h)					
(a) Children	160	(4 5–370)	–	36	Values from (a) 11, (b) 28 subjects Often increased when absorption of carbo hydrate is disturbed
(b) Adults	32 4	0–76,4	22	48	
Phenols (mg/24 h)	–	(20–80)	–	49	Breakdown products of aromatic amino acids

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Total fats (g/24 h)					
(a) Children, 2 months–6 years	–	(0.29–1.79)	–	6	Values from (a) 44 children by the SPERRY method, (b) 14 and (c) 24 adults b the method of VAN DE KAMER et al.[52]. On a fat-free diet the daily fat excretio is about 2 g[53]. In adult stools about 15% of the lipids are in the bacteri fraction[12]. The fat content is *increased* in various forms of malabsorption, i too rapid passage of food through the intestine, in biliary and pancreati disease and in obstruction of the flow of lymph from the intestine. Steatorrhoe is better diagnosed by determining the fat content of the 24-hour stools tha from the dry substance[4]; the microscopic examination of undigested foo residues is diagnostically useless[4,54].
(b) Adults	5.54	0.14–10.94	2.7	51	
(c) Adults	4.0	0.8–7.2	1.6	7	
As percentage of dry substance					
(a) Children, 2–6 months	–	(5.2–43.1)	–	6	
(a) Children, 6 months–6 years	–	(6.1–25.8)	–	6	
(c) Adults	13.3	–	8.07	7	
Free fatty acids (g/24 h)					
(a) Children, 2 months–6 years	–	(0.14–1.38)	–	6	
(b) Adults	3.96	–	2.28	50	
Volatile fatty acids (mEq/24 h)	–	(9.8–31.2)	–	55	Acetic, propionic, butyric, valeric and other volatile fatty acids arise fron bacterial decomposition of carbohydrates in the intestine; they are *increased* i sprue.
Neutral sterols					
Meconium (g/kg)	7.9	–	–	56	The ratio of sterol esters to free sterols is about 0.15. In adults the sterol consist of about 60% coprosterol, 15% cholesterol + cholestanol, 4% 7-de hydrocholesterol + Δ^7-cholestenol, 17% plant sterols[63].
Children's stools (g/24 h)					
1st week	0.24	–	–	56	
7 weeks–10 months	0.10	–	–	56	
Adult stools (g/24 h)	–	(0.39–0.76)	–	57	
Bile acids (g/24 h)	–	(0.27–0.48)	–	57	Estimated range. The following bile acids have been identified in faeces[58]: chenodeoxycholic acid, cholic acid, deoxycholic acid and lithocholic acid. The bile acid content varies with the nature of the nutrient fat[59].
Vitamins					
Vitamin B$_6$ (mg/24 h)					
Infants	–	(0.15–0.30)	–	60	
Adults	–	(0.7–0.9)	–	60	
Vitamin B$_{12}$ (μg/24 h)	~10	–	–	61	
Ascorbic acid (mg/24 h)	–	(< 10)	–	62	

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The physical properties and chemical composition of urine are :ry variable and change considerably with the amount and nature 'the diet, while the amounts of endogenous metabolites present :pend also on the body weight. The composition of individual ·ine samples does not tally precisely with the that of the 24-hour :ine since the excretion of many constituents is subject to a day-id-night rhythm[1-3]. Unless otherwise stated, the data given in us chapter are for adults on a mixed diet. There is an extensive terature on the properties and composition of urine[4-6].

.ppearance

At the moment of voiding, the urine is usually clear and trans-arent, though a highly alkalinizing meal may sometimes cause it ɔ be more or less cloudy When clear urine has stood for a while a occulent turbidity (nubecula) appears, this is due to the presence if mucus from the urinary tract and, in alkaline urine, of various rystals (metallic phosphates) Turbidity of the urine may also be lue to lipids.

The cell content of urine is discussed on page 677, urinary sedi-nents on pages 677–678.

:olour

Urine normally has a more or less intense yellow colour, but the

[illegible]

severe sweating

Yellowish red to brick red In the presence of urobilinogens or por-

[illegible]

sulphonphthalein

Blue In the presence of indigo carmine.

Odour

[illegible]

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Amount (ml/24 h)					
Newborn, infants					
1 day	17	(0–68)	–	8	Values from (a) 60, (b) 40 and (c) 27 subjects (the last group over 90 years of age) At birth the bladder contains up to 44 ml (mean 5 7 ml) of urine[12]. Premature infants secrete less urine than full-term infants of the same age[13]. The secretion of urine is *increased* on a high [illegible]
2 days	34	(0–84)	–	8	
3–10 days	–	100–300	–	9	
10 days–2 months	–	250–450	–	9	
2–12 months	–	400–500	–	9	
Children					
1–3 years	–	500–600	–	9	
3–5 years	–	600–700	–	9	
5–8 years	–	650–1000	–	9	
8–14 years	–	800–1400	–	9	
(a) Men	1015	(510–2000)	–	10	
(b) Women	989	(500–1875)	–	10	
(c) Aged persons	853	(273–2400)	–	11	
(ml/kg body weight/24 h)					
(a) Newborn, 1st day	8 5	1 5–15 5	3 5	16	Values from (a) 9 infants, (b) 16 infants (breast-fed) and (c) 11 men
(b) Newborn, 7th day	76	42–110	17	16	
(c) Young men	20	13 6–26 4	3 2	16	
Specific gravity					
Newborn, first days	1 012	–	–	8	The specific gravity of individual samples of urine can vary between 1 001 and 1 050[4] For calculation of the amounts of solutes from the specific gravity see under 'Dry substance' on page 662 The maximum specific gravity in the fluid deprivation test is discussed under 'Renal Function Values' on page 530 The specific gravity of urine is greatly *reduced* in diabetes insipidus but *increased* in diabetes mellitus, fever and the nephrotic syndrome (as a result of proteinuria)
Infants	–	(1 002–1 006)	–	9	
Adults	–	(1 010–1 025)	–	17	
Relative viscosity	–	(1.0–1 14)	–	18	see table below
Surface tension (dyn/cm⁻¹)	–	(64–69)	–	4	

Specific gravity	Relative viscosity	
1 005	1 0	(Viscosity of distilled water = 1 00)
1 016	1 02	
1 022	1 09	
1 024	1 14	

The viscosity is increased when the urine contains increased amounts of albumin, blood or erythrocytes

	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks
Freezing-point depression (°C)					
(a)	–	(0.1–2.5)	–	19	Values (a) are for the limiting dilution and concentration capacities of ı neys, values (b) for adults with maximum urinary concentration. For n of determination see JOHNSON et al.[21]. The osmolarity and osmolality (are almost equal. *Newborn infants, and particularly premature infants,* c centrate the urine only up to 700–1100 mosm/l depending on the urea c tration[22].
(b)	–	(1.6–2.5)	–	20	
Osmolarity (mosm/l)					
(a)	–	(50–1400)	–	19	
(b)	–	(855–1335)	–	20	
pH value					
Newborn	6.2	–	–	23	Normal urine usually has an acid reaction due to the phosphoric and sul acids arising from breakdown of proteins. On a vegetable diet it may b alkaline as a result of breakdown of organic acids from fruit and vegeta bicarbonate. The pH value (and the titratable acidity) is subject to a da night rhythm[1,26]. The urine is least acid (sometimes alkaline) on wak *the morning and most acid towards midnight. It may also become* al owing to bacterial decomposition of urea.
Infants	6.0	(5.1–6.8)	–	23, 24	
Children	–	(5.3–7.2)	–	24	
Men	5.7	(4.8–7.5)	–	19, 25	
Women	5.8				
Titratable acidity (mEq/kg body weight/24 h)					
(a) Newborn	0.30	–	–	23	Titration up to pH 7.4; values from (a) 20, (b) 220 and (c) 11 subject: titratable acidity depends on the amounts of acids (uric, lactic and keto and primary phosphates present. In the newborn the urine has only a titratable content[16,28]. In adults the total acidity (titratable acidity + NH a mixed diet averages 50–60 mEq/24 h[29] (see also pages 535–536). In s nonrenal acidosis up to 1000 mEq hydrogen ions may be excreted daily, wh alkalosis bicarbonate excretion may result in a daily saving of up to 250 hydrogen ions. In stationary renal acidosis an average of 19 mEq hydı ions is retained daily[30].
(b) Infants	0.96	–	–	23	
(c) Young men	0.64	0.39–0.89	0.125	16	
Men (mEq/24 h)	38	(20–40)	–	25, 27	
Women (mEq/24 h)	28				
Dry substance (g/24 h)	–	(50–72)	–	2	The amount of solutes in the urine can be calculated roughly from the sp gravity by multiplying the second and third decimal places by 2.6 (1. small children). Example: specific gravity 1.020; dry weight ≅ 20 × 2 52 g/24 h (adults)[6].

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Inorganic substances (for references see pages 664–665)

	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks
Chloride (mEq/kg body weight/24 h)					
(a) Newborn, 1st day	0.43	0.07–0.79	0.18	1	Values from (a) 9 infants, (b) 16 infants (breast-fed) and (c) 11 men. Ab 80–95% of the ingested chloride is excreted in the urine. The chloride excreti is *increased* on a high-salt diet, by the action of diuretic agents, in renal tubu injury (salt-losing nephritis) and in ADDISON's disease; it is *decreased* on lo salt diets, in chloride loss due to vomiting, sweating or diarrhoea, in CUSHIN *syndrome and corticosteroid* treatment, and in all forms of salt retention su as oedema.
(b) Newborn, 7th day	2.08	0.08–4.08	1.00	1	
(c) Young men	2.80	1.56–4.04	0.62	1	
Men (mEq/24 h)	184	(120–240)	–	2, 3	
Women (mEq/24 h)	132				

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Phosphorus (mg/kg body weight/24 h)					
(a) Newborn, 1st day	0.12	0.06–0 18	0 03	7	Values from (a) 9 infants, (b) 16 infants (breast fed, about 10 times higher on cow's milk) and (c) 11 men The urine secreted in utero contains only little phosphorus[7]. About 95–100% of the urinary phosphorus is in the inorganic
(b) Newborn, 7th day	0.32	0–0.7	0 19	7	
(c) Young men	16.5	10.1–22.9	3 2	7	
Adults (g/24 h)	–	(0 8–2.0)	–	4	phate reabsorption, or the phosphate excretion index[9], for values measured in children see JANSE et al [10]. For further data on phosphorus excretion see NORDIN[11] and BORLE[11]
Sulphur (g/24 h)					
Total S	1.32	(1 24–1 49)	–	12	
Inorganic sulphate-S	1.17	(1 07–1.30)	–	12	
Sulphuric ester-S	0 09	(0 08–0 10)	–	12	
Neutral S	0 07	(0 05–0 08)	–	12	
Inorganic sulphate-S (mg/kg body weight/24 h)					
(a) Newborn, 1st day	3 4	0–6 8	1.7	7	
(b) Newborn, 7th day	6 0	1 8–10 2	2.1	7	
(c) Young men	19.2	10.8–27.6	4 2	7	
$SO_4^{=}$ (mEq/24 h)					
Men	45	(30–70)	–	2 3	
Women	36				
Bromide (mg/l)	6 56	(2 97–8 55)	–	15	Values from 8 subjects
Fluoride (mg/l)					
(a) Children, 1–3 years	0 14	(0 05–0.30)	–	16	Values from (a) 31 infants, (b) 28 infants, (c) 34 adults with a drinking-water fluoride content of 0 5–0 6 mg/l, (d) 5 adults with a fluoride intake of 1 5–4 7 mg/24 h. Fluoride excretion falls at the 4th month of pregnancy (to 0 22 mg/l at the 8th month) and rises after parturition to normal in 16 weeks[18]
(b) Children, 4–6 years	0 27	(0 05–0 70)	–	16	
(c) Adults	0 52	(0.30–0 85)	–	16	
(d) Adults (mg/24 h)	–	(0 9–2 9)	–	17	
Iodide (mg/24 h)	0 191	(0 018–0.483)	0 138	19	
Thiocyanate (mg/l)	4	(0–6)	–	20	In nonsmokers, higher in smokers.
Cyanide (µg/24 h)	–	(2–6)	–	21	
Carbon dioxide (mmol/24 h)	–	(0 3–3 0)	–	3	In physical solution in urine at pH 5 5–6 0, with rising pH carbon dioxide is increasingly present as bicarbonate See also under 'pH value' and 'Titratable acidity' above
Potassium (mEq/kg body weight/24 h)					
(a) Newborn, 1st day	0 36	0 08–0 64	0 14	7	
(b) Newborn, 7th day	0 95	0–2.25	0 65	7	
(c) Young men	1 05	0 79–1 31	0 13	7	
Men (mEq/24 h)	57	(35–80)	–	2 3	
Women (mEq/24 h)	47				
Sodium (mEq/kg body weight/24 h)					
(a) Newborn, 1st day	0.25	0 11–0 39	0 07	7	
(b) Newborn, 7th day	1.78	0–4.36	1.29	7	
(c) Young men	2.66	1 58–3 74	0 54	7	
Men (mEq/24 h)	177	(120–220)	–	2 3	
Women (mEq/24 h)	128				

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Calcium (mEq/kg body weight/24 h)					
(a) Newborn, 1st day.......	0.02	0.01–0.03	0.005	24	Values from (a) 12 infants, (b) 9 infants (breast-fed; about one-half as much on cow's milk), (c) 104 children, (d) 121 adults and (e) 13 adults. 0–33%, mean 22%, of the urinary calcium is ionized, the remainder bound to organic acids[29]. Calcium excretion is subject to a day-and-night rhythm with a maximum during the morning and a minimum during the night[7,8], probably an effect of meals[30]. It is more dependent on the degree of absorption from food than on the calcium content of the diet; with an intake of 700 mg calcium per day about 30% is excreted in the urine. In adults the calcium excretion is *decreased* when the calcium content of the diet is low and also in persons of advanced age[31]. Unlike the serum calcium level, calcium excretion does not change significantly during pregnancy[32]. It is pathologically *increased* in hyperparathyroidism, various forms of osteoporosis, bone metastases, tubular acidosis, idiopathic hypercalcaemia and vitamin-D poisoning, *decreased* when the calcium serum level is low (as in hypoparathyroidism and osteomalacia with steatorrhoea) and in renal insufficiency (for instance in the nephrotic syndrome). On calcium excretion see the literature[11,33].
(b) Newborn, 7th day	0.26	0.18–0.34	0.04	25	
(c) Children, 1 year	0.10	(0.01–0.40)	–	26	
(d) Adults	–	(0.05–0.31)	–	27	
(e) Adults (mEq/24 h)......	11.5	6.5–16.5	2.5	28	
Magnesium (mEq/kg body weight/24 h)					
(a) Newborn, 1st day.......	0.004	0.0004–0.0076	0.0018	24	Values from (a) 12 infants, (b) 13 infants (breast-fed; about one-half as much on cow's milk), (c) 91 men, (d) 61 women. The magnesium excretion is subject to a day-and-night rhythm with a maximum during the morning and a minimum during the night[8,37], probably an effect of meals[30]. Of the magnesium in the diet about one-third is absorbed and excreted in the urine. An increase in magnesium excretion has been recorded during medication with diuretic agents[38].
(b) Newborn, 7th day	0.050	0–0.118	0.034	34	
(c) Men (mEq/24 h)........	10.7	4.7–16.7	3.0	35	
(d) Women (mEq/24 h).....	8.8	3.4–14.2	2.7	35	
(e) Adults (mEq/24 h)......	–	(4.9–16.5)	–	36	
Iron (µg/24 h)					
(a)......................	55	–	–	39	Values (b) from 10 subjects determined with bathophenanthroline. The iron arises mainly from erythrocytes and from epithelial cells of the renal tubules and vesical mucosa. Iron excretion is increased in diseases involving intravascular haemolysis[41].
(b)......................	100	(40–150)	–	40	
Copper (µg/24 h)					
(a) Children..............	12	(6–17)	–	42	Values from (a) 12 children, (b) 20 adults, (c) 12 adults and (d) 16 subjects; values (a) and (b) determined with oxalyl dihydrazide, (c) with dithizone, (d) by neutron activation analysis. Copper excretion is at a maximum in the afternoon. It is pathologically *increased* in WILSON's disease, portal vein cirrhosis and proteinuria (for instance in the nephrotic syndrome), with 60–80% of the copper present as caeruloplasmin.
(b) Adults	14	(8–22)	–	42	
(c) Adults	18	3.6–32.4	7.2	43	
(d)......................	50.4	28.2–72.6	11.1	44	
Manganese (µg/24 h)	0.8	0.2–1.4	0.3	44	Values from 16 subjects determined by neutron activation analysis. See also KEHOE et al.[45] and SCHROEDER[46].
Molybdenum (µg/l)	16.3	0–42.7	13.2	47	Values from 16 subjects determined by emission spectrography. See also SCHROEDER[46] and MELTZER et al.[48].
Zinc (µg/24 h)					
(a)......................	457	217–697	120	49	Values from (a) 14, (b) 16 subjects. Zinc excretion is increased in liver cirrhosis due to alcohol[49], in diabetes[48] and in cancer[47].
(b)......................	430	138–722	146	47	
Other elements	...	...	...	...	Urine also contains silicate[5], nitrite and nitrate[5], and borate[50]. The arsenic content is normally less than 0.1 mg/l[51], the lead content 30–80 µg/l[46,52]; the mercury content should not exceed 30 µg/l[53]. The following elements have also been determined in urine: aluminium[45], cadmium[46,48,50], chromium[46,50], cobalt[48], nickel[45,46,50,54], silver[46], strontium[24,25,55], titanium[46], vanadium[46], bismuth[48] and tin[45,46,48].

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litrogenous substances (for references see pages 671–672)

	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks
Total nitrogen (g/l)					
(a) Newborn, at birth	0 74	0 02–1.46	0.36	*1*	
(b) Newborn, 2nd day	6 40	3.44–9 36	1 48	*1*	
(c) Adults	9 19	–	–	*2*	
(mg/kg body weight/24 h)					
(b) Newborn, 1st day	38 9	2.1–75 7	18 4	*1*	
(b) Newborn, 2nd day	75 4	23 6–127	25 9	*1*	
(d) Newborn, 7th day	108	65 8–150	21 1	*1*	
(e) Young men	207	159–255	24 2	*1*	
(g/24 h)					
(f) Children, 3–11 years	–	(5 3–20 9)	–	*3*	
(g) Adults	11.5	6 9–16 1	2.3	*4*	
Urea (mg/kg body weight/24 h)					
(a) Newborn, 0–2 days	39	–	–	*2*	
(b) Newborn, 4–6 days	73	–	–	*2*	
(c) Adults	358	–	–	*2*	
(d) Adults (g/24 h)	20 6	12 6–28 6	4 0	*4*	
Creatine (mg/kg body weight/24 h)					
(a) Premature infants, 2–12 weeks	2 3	(0 3–4 3)	–	*6*	
(b) Newborn, 2–12 weeks	28 0	(15 2–35 8)	–	*7*	
(c) Infants, 6–12 months	10 6	(3 6–15 3)	–	*7*	
(d) Children, 6–11 years	4 0	(2.2–7 4)	–	*8*	
(mg/24 h)					
(e)	–	(0–50)	–	*9*	
(f)	–	(18 6–58 5)	–	*10*	
(g) Men	52.1	(11–189)	–	*11*	
(g) Women	92.1	(19–270)	–	*11*	
(h) Persons over 90 years	90	(25–230)	–	*12*	
Creatinine (mg/kg body weight/24 h)					
(a) Premature infants, 2–12 weeks	14 3	(8.3–19 9)	–	*6*	
(b) Newborn, 2–12 weeks	11 9	(11 0–14 6)	–	*7*	
(c) Infants, 6–12 months	9 8	(5 2–20 4)	–	*7*	
(d) Children, 6–11 years	16.3	(6 4–21 9)	–	*8*	
(g/24 h)					
(e) Men, 20–45 years	1 80	1 1–2.5	0 35	*13*	
(f) Women, 20–45 years	1 17	1 01–1.33	0 08	*13*	
(g) Persons over 90 years	0 47	(0 04–1 0)	–	*12*	

Urine – Nitrogenous Substances

(For references see pages 671–672)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Guanidine (mg/24 h)	–	(<2)	–	16	
Guanidinoacetic acid					
(a) Newborn, 2–12 weeks (mg/kg body weight/24 h)	2.6	(1.7–3.6)	–	17	Values (a) by chromatographic separation in 11 infants, (b) colorimetrically in 5 adults.
(b) Adults (mg/24 h)	27	(11–56)	–	18	
Methylguanidine (mg/24 h)	–	(<1)	–	16	
Ammonia (mg/24 h)					
Men	680	(340–1200)	–	19	Values from (a) 9 infants, (b) 16 infants (breast-fed) and (c) 11 men. Abnormally low values are found in alkaline urine as a result of loss of ammonia, abnormally high values in old urine samples as a result of bacterial formation of ammonia. The ammonia excretion is proportional to the anionic content of the diet (for instance phosphates and sulphur in meat); it is therefore higher in acid than in alkaline urine. It is pathologically *increased* in metabolic and respiratory acidosis, *decreased* in metabolic and respiratory alkalosis and in injury to the distal renal tubules.
Women	510				
(mEq/24 h)					
Men	40	(20–70)	–	19	
Women	30				
(mEq/kg body weight/24 h)					
(a) Newborn, 1st day	0.26	0.02–0.50	0.12	1	
(b) Newborn, 7th day	0.56	0.26–0.86	0.15	1	
(c) Young men	0.80	0.52–1.08	0.14	1	
Amino acids, total					
(mg/24 h)	2255	(1337–3150)	–	20	Calculated from the amounts of the individual amino acids in hydrolysed urine.
(mg α-amino-N/24 h)	261	–	–	20	
Amino acids, free (mg/24 h)					
(a)	800	(350–1180)	–	21	Values (a) calculated from the amounts of the individual free amino acids (see the table on page 667); values (b), (d), (e) determined colorimetrically with ninhydrin; values (c) determined as the copper complex; values (d) from 8, (e) from 18 subjects. For details see page 667.
(mg α-amino-N/24 h)					
(b) Children, 2–4 years	33	(16–54)	–	22	
(a) Adults	90	(41–133)	–	21	
(mg α-amino-N/kg body weight/24 h)					
(c) Premature infants, 2–12 weeks	20.7	(10.0–26.8)	–	6	
(c) Newborn, 2–12 weeks	12.9	(6.8–20.7)	–	7	
(c) Infants, 6–12 months	6.3	(3.4–8.5)	–	7	
(c) Children	1.8	(0.9–2.9)	–	23	
(a) Adults	1.4	(0.6–2.1)	–	21	
(mg α-amino-N/mg creatinine-N)					
(d) Children	0.46	0.14–0.78	0.16	24	
(e) Adults	0.17	0.08–0.26	0.045	24	
Amino acids, bound (excluding peptides)					
o-Aminohippuric acid (mg/24 h)	1.14	(0.4–1.7)	–	28	Values from 20 subjects. See also under '*o*-Aminobenzoic acid', page 669.
Hippuric acid (g/24 h)	–	(1.0–2.5)	–	29	Represents about 70% of the bound glycine. The benzoic acid from which the hippuric acid arises mostly originates from aromatic components of vegetable foods. Hippuric acid excretion is *increased* after ingestion of large amounts of fruit and vegetables, pathologically *decreased* in renal insufficiency.
m-Hydroxyhippuric acid (mg/24 h)	6	(2–150)	–	30	
Phenylacetylglutamine (g/24 h)	–	(0.25–0.50)	–	29	Represents about 50% of the bound glutamic acid. The phenylacetic acid formed by bacterial decomposition of protein is excreted as phenylacetylglutamine.
Peptides (mg/24 h)					
Anserine	–	(5–7)	–	31	For a summary of data see SKARŻYŃSKI and SARNECKA-KELLER[33].
Carnosine	–	(2–3)	–	31	
Homocarnosine	1.1	(0.5–2.4)	–	32	
Peptides containing hydroxyproline (as hydroxyproline)	25.1	(14.0–38.7)	–	34	Values from 12 adults. The excretion is increased in growing children[35]. Only traces of free hydroxyproline are present in urine. The hydroxyproline excretion is a measure of the collagen metabolism.

Amino acid	mg/24 h						µmol/kg body weight/24 h ***				
	Children* (9–24 months)		Men**		Women**		Premature infants, bottle-fed	Full-term babies and Infants		Children	Adults
	Mean	Extreme range	Mean	Extreme range	Mean	Extreme range		Bottle-fed	Breast fed		
Alanine	10	5–15	22	5–32	24	9–44	18 6–125	14 2–30.2	9 6–15.3	3 2–18.2	3.6–9.8
β-Alanine	ca. 0 3	–	6	3–10	3	2–9	–	–	–	–	–
α-Aminoadipic acid	ca. 0.5	–	8	5–13	4	0–13	–	–	–	–	–
α-Aminobutyric acid	ca 0 3	–	–	–	–	–	–	–	–	–	–
γ-Aminobutyric acid	ca. 0.3	–	–	trace	–	trace	–	–	–	–	–
β-Aminoisobutyric acid	5	0–9	22	6–37	29	10–52	–	<2.7	3 2–12 2	1 4–9 4	–
Arginine	ca 0 5	–	6	0–14	4	0–11	<3 1	<1.3–7.1	<1 0	–	<0.7–2.0
Asparagine	–	–	–	–	–	–	–	–	–	–	3.9–7.8
Aspartic acid	–	<4	8	3–29	4	2–11	–	–	–	–	<1.2
Citrulline	–	–	–	–	–	–	–	3 9–6 2	4.4	–	–
Cystine	–	–	–	–	–	–	<3 1–8 1	1.1–7 7	<2 9	0 6–4 1	<0.5–1.2
Cystine+cysteine†	–	<4	14	3–33	6	0–13	–	–	–	–	–
Glutamic acid	–	–	–	–	–	–	2.3–31	2.3–13 1	5.2	1.5–1 6	<0.7–2.8
Glutamine	–	–	–	–	–	–	–	–	–	4 0–33.4	–
Glutamine+asparagine	25	2–60	73	42–103	62	43–88	–	–	–	–	–
Glutamine+asparagine +serine	–	–	–	–	–	–	21 0–264	8 9–60 0	13 8–14.5	–	–
Glycine	28	11–42	104	53–189	142	67–312	42 6–484	46 0–117	27.6–33 8	4 3–53 1	13 8–36.6
Histidine	47	15–83	138	20–213	128	79–208	13.7–34 5	9 3–56 0	18.9–22 8	8 0–46.0	11.9–22.5
Homocitrulline††	10	1–65	–	trace	–	trace	–	–	–	–	–
Hydroxyproline†††	–	0 8–1 4	–	<0 5	–	<0 5	–	–	–	–	–
Isoleucine	–	<4	15	8–24	10	5–20	2 5–16.8	1 3–2.3	<1 5	0 5–2 3	1.1–2 7
Leucine	–	<4	11	6–20	9	2–16	3 2–21	2.5–6 6	<3.7	0 7–3 1	1.0–2.3
Lysine	10	1.5–20	7	0–14	8	0–16	–	–	–	1.8–23 5	0.7–4.5
Lysine+1-methylhistidine	–	–	–	–	–	–	10 6–35	7.0–27.0	9.7–10 1	–	–
Methionine	–	<5	7	5–11	5	3–12	<2 6	0 5–1 3	<1.0	0 6–3 9	<0 6–1.2
1-Methylhistidine	9	0–43	73	22–114	65	26–155	–	–	–	0 8–9.8	–
3-Methylhistidine	–	<5	65	35–87	48	30–69	5.1–5 2	2 2–4 7	2 1–5 2	1.5–8 9	–
Ornithine	–	<4	1	0–4	2	0–11	–	–	–	–	–
Phenylalanine	–	<5	13	8–15	13	6–41	2 4–28	1 3–4 5	2 0–3 1	0.8–4.4	0.8–2 6
Proline	ca 0 3	–	–	–	–	–	0–108	0–37.6	0	0	<1.4
Serine	10	7–13	42	27–65	37	22–61	–	–	–	4 1–22 4	3 9–7.8
Taurine	7	2–14	123	44–231	87	27–161	<31	<16 5	3 5–7.3	2 2–45 3	9.1–38.6
Threonine	6	3–9	17	2–35	23	5–33	11.3–140	4 0–20 0	3 8–5 6	2 4–10 3	1.9–5 0
Tryptophan§	–	–	21	10–32	16	5–27	–	–	–	–	–
Tyrosine	–	<5	19	7–27	15	9–26	12 6–61	2 0–14 0	1.1–2.9	1.3–7 0	1.3–4 3
Valine	ca 0.3	–	10	4–17	6	0–30	1.9–23	<3 7	<1.9	0 5–2.0	<1 4

* Values from 8 boys and 7 girls determined by ion exchange [illegible] ... [illegible] page 30).

† Cystine 10–15 mg/l, cysteine 2–4 mg/l, determined by ion exchange (BRIGHAM et al. *J clin Invest*, [illegible]) [illegible]

§ Determined microbiologically (ULRICH, J A, *Proc Mayo Clin*, 29, 210 [1954])

Urine – Nitrogenous Substances

(For references see pages 671–672)

	Mean	95% range (*extreme range* in brackets)	*s*	Reference	Remarks
Proteins (mg/24 h)					
Total non-dialysable material					
(a) Newborn	87.9	34.3–142	26.8	36	Values from (a) 7, (b) 3, (c) 11, (d) 7 subjects; values (a, b, c) by fractionat into protein and uromucoid by millipore filter; values (d) calculated from N-content of the non-dialysable material; values (e) by the biuret reaction values (f) include about 80% chondroitin sulphate A. The discrepancy in values for high-molecular substances (between 30 and 750 mg/24 h[47]) are in large part to the difficulty of concentrating the urine. These substances clude 30–40% of carbohydrates[37,42], i.e., glycoproteins, glycopeptides mucopolysaccharides. In electrophoretic separation of the proteins about 2 appear in the albumin fraction, 17% in the α_1-globulin fraction, 24% in α_2-globulin fraction, 16% in the β-globulin fraction and 12% in the γ-glo lin fraction[43]. Up to 25 serum proteins have been identified in urine[44], cluding transferrin, γA-globulin and γG-globulin and also low-molecu γ-globulin chains; the other proteins present arise from the kidneys[45]. T urinary protein content is physiologically *increased* in the newborn[46] (part ularly in premature infants), after standing erect with hyperlordosis following physical effort; it is pathologically *increased* in fever, severe shock renal diseases (particularly the nephrotic syndrome[47]). In multiple myelo a low-molecular protein (Bence-Jones protein; for identification see Snapp and Ores[48] and Naumann[49]) often appears in readily identifiable amou (precipitation with sulphosalicylic acid, disappearance of the precipitate 90–100 °C). For a detailed discussion of the proteins and mucopolysacchari of urine see the literature[41,49].
(b) Infants	125	–	–	36	
(c) Adults	474	420–528	27	36	
(d)	433	203–663	115	37	
Proteins					
(a) Newborn	10.5	8.82–12.2	0.84	36	
(b) Infants	13.0	–	–	36	
(c) Adults	61.6	47.0–76.2	7.3	36	
(d)	204	–	–	37	
(e)	–	(30–60)	–	38	
Uromucoids					
(a) Newborn	4.75	3.27–6.23	0.74	36	
(b) Infants	14.8	–	–	36	
(c) Adults	70.5	47.7–93.3	11.4	36	
Mucopolysaccharides					
(f)	–	(3–15)	–	39	
Amines, betaines					
Ethanolamine (mg/24 h)					
(a) Children, 3–11 years	13.1	(3.6–18.7)	–	3	Determined (a) by column chromatography on 12 children, (b) by paper chr matography on 14 adults. Phosphoethanolamine occurs in the urine when t blood phosphatase level is low[50].
(b) Adults	20.6	(11.5–35.2)	–	18	
Methylamine (mg/24 h)	5.0	(4.6–6.0)	–	51	
Dimethylamine (mg/24 h)	17.0	(15.2–19.3)	–	51	
Cystamine (mg/24 h)	1.4	–	–	52	
Piperidine (mg/24 h)	5.7	(4.7–7.1)	–	51	Probably in the main of bacterial origin (large intestine)[53].
Choline (mg/24 h)	–	(5.6–9.0)	–	54	Present exclusively in the free form.
Carnitine (mg/24 h)	–	(80–130)	–	55	
Acetonitrile (μg/l)	2.9	–	–	56	Values from nonsmokers; in smokers 118 μg/l.
Tyramine (mg/24 h)	1.3	(0.8–2.6)	–	57	Probably in the main of bacterial origin (large intestine)[53].
Para-aminobenzoic acid (mg/24 h)	0.76	(0.31–1.32)	–	58	
Catecholamines (μg/24 h)					
Adrenaline free	1	–	–	59	Calculated from measurements on 41 samples of nocturnal urine. The cate cholamines in urine are partly free, partly bound to sulphuric or glucuroni acid. See also page 733.
Noradrenaline free	57	–	–	59	
Dopamine free	197	–	–	59	
Metanephrine free	30	–	–	59	
Metanephrine total	88	–	–	59	
Normetanephrine free	205	–	–	59	
Normetanephrine total	420	–	–	59	
Tryptophan metabolites	...	...	...	...	In vitamin B_6 deficiency (see also pages 475–476) there is increased excretio of xanthurenic acid and other tryptophan metabolites, particularly after or administration of tryptophan (tryptophan loading test)[60,61].
3-Hydroxyanthranilic acid (mg/24 h)	0.36	(0.1–1.1)	–	61	

Urine – Nitrogenous Substances

(For references see pages 671–672)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Hydroxykynurenine (mg/24 h)	0 49	(0–2.3)	–	61	In women the excretion of this substance falls after menstruatic
Acetylkynurenine (mg/24 h)	2 2	–	–	62	Values from 7 women
Kynurenine (mg/24 h)					
(a) Infants	2.32	(0 19–27 7)	–	63	Values from (a) 17, (b) 19, (c) 20 subjects
(b) Children	1.8	(0 50–3.8)	–	64	
(c) Adults	1.14	(0 3–2 6)	–	61	
Kynurenic acid (mg/24 h)					
(a) Infants	1 81	(0–4 75)	–	63	Values from (a) 17, (b) 19, (c) 20 subjects
(b) Children	5 0	(0 00–8.8)	–	64	
(c) Adults	2 83	(1 0–4 2)	–	61	
Xanthurenic acid (mg/24 h)					
(a) Children	6 4	(3 2–13 0)	–	64	Values from (a) 19, (b) 20 subjects. Found in only one of a gro (1 5 mg/24 h)[63].
(b) Adults	0.66	(0 3–1 8)	–	61	
o-Aminobenzoic acid (anthranilic acid) (mg/24 h)	0 89	(0 32–2 24)	–	66	Mainly present as o-aminohippuric acid (see page 666)
Nicotinic acid			..		See under 'Vitamins', page 477
Indoles					
Tryptamine (µg/24 h)					
(a) Children	–	(66–370)	–	65	Values from (a) 20, (b) 13, (c) 6 subjects Probably in the ma origin (large intestine)[53]
(b) Men	64	(20–120)	–	66	
(c) Women	56	(40–72)	–	66	
***N,N*-Dimethyltryptamine** (µg/24 h)	43 0	25 8–60 2	8 6	67	Values from 50 subjects
Serotonin (5-hydroxytryptamine) (µg/24 h)					
Free					
(a) Children	83	(43–123)	–	64	Values from (a) 6, (b) 20, (c) 6, (d) 21 subjects The excretion serotonin in particular is increased in carcinoid tumours
(b) Men	72	(45–110)	–	66	
(c) Women	55	(10–85)	–	66	
(d)	131	(31–296)	–	68	
As glucuronide	93	(21–355)	–	68	
As sulphate	59	(0–127)	–	68	
5-Hydroxyindoleacetic acid (mg/24 h)					
(a) Children	8 6	(1 4–13 2)	–	64	
(b) Adults	–	(1 0–14 7)	–	69	
(c) Adults	4 5	2 3–6 7	1 1	70	
5-Methoxytryptamine	0	–	–	64	50 µg/24 h has been found in the urine of a rheumatic fever
Bufotenine (µg/24 h)	63	49–77	7	72	Values from 50 subjects
Indoxylsulphuric acid (mg/24 h)					
(a) Children	420	(143–620)	–	64	
(b) Adults	200	(140–250)	–	64	
(c) Men	64	28–100	18	74	
(d) Women	57	13–101	22	74	
6-Sulphatoxyskatole (mg/24 h)	24	(5–130)	–	68	

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Indole-3-acetic acid (mg/24 h)					
(a) Total	–	(5.2–13.8)	–	77	Values from (a, b) 11 subjects; (a) after hydrolysis of the urine.
(b) Free	–	(3.1–8.1)	–	77	
Indole-3-lactic acid (mg/24 h)	–	(0.3–3)	–	78	
Indoleacetylglutamine (mg/24 h)	–	(1–8)	–	78	
Indoleformylglucuronide (mg/24 h)	–	(0–60)	–	79	
Imidazoles, histidine metabolites					
***N*-Acetylhistamine** (μg/24 h)					
(a) Children	–	(17–1840)	–	65	Values from (a) 20, (b) 17 subjects. Probably in the main of bacterial o (large intestine)[53].
(b) Adults	22.0	(2.3–56)	–	80	
Histamine (μg/24 h)	11.9	(6.1–19)	–	80	The excretion of histamine and its metabolite 1,4-methylimidazoleacetic is considerably increased in mastocytosis[81, 82].
	–	(5–30)	–	81	
Imidazolelactic acid (mg/g creatinine)	19.8	9.6–30.0	5.1	83	Values from 12 subjects.
Urocanic acid (mg/24 h)	0.62	(0–1.7)	–	84	
Formiminoglutamic acid (formamidinoglutaric acid) (mg/24 h)	1.25	(0–2.1)	–	84	The excretion of this histidine metabolite is *increased* in folic acid defici (see page 479), sometimes also in vitamin B_{12} deficiency, diseases of the and sarcoidosis.
Porphyrins and related compounds					
Aminoacetone (mg/l)	2.2	(1.5–3.1)	–	85	
δ-Aminolaevulinic acid					
(a) Children (mg/l)	2.57	0.27–4.87	1.15	86	Values from (a) 50 children under 15 years, (b) 100 adults, (c) 13 adults. Or excretion in children of various ages see Kaser et al.[89]. It is *increased* in s porphyrias[90] (see also pages 454–455) and in lead poisoning. Determinatio this component in urine enables an increased absorption of lead to be re nized in time; concentrations of 13–20 mg/l urine correspond to 150–200 of lead per litre of urine and indicate that lead poisoning is imminent.
(b) Adults (mg/l)	2.9	0.1–5.7	1.4	87	
(c) Adults (mg/24 h)	2.63	0–5.33 (1.43–6.97)	1.35	88	
Porphobilinogen					
(a) Children (mg/l)	1.05	0.13–1.97	0.46	86	Values from (a) 50 children under 15 years, (b) 100 adults, (c) 13 adults. the excretion in children of various ages see Käser et al.[89]. It is *increas* some porphyrias[90] (see also pages 454–455) and there is a slight increas liver disease; it is not increased in lead poisoning.
(b) Adults (mg/l)	1.0	0–2.0	0.5	87	
(c) Adults (mg/24 h)	1.40	0.38–2.42	0.51	88	
Coproporphyrin					
(a) (μg/l)	70	0–150	40	87	Values from (a) 100, (b) 9, (c) 72 subjects. Spectrophotometric methods g lower values than fluorometric methods (b)[93]. The excretion of copro phyrin is proportional to the body weight[91]. 50–90% of the urinary co porphyrin consists of coproporphyrin III, 10–40% of coproporphyrin The excretion is *increased* in some porphyrias[90] (see also pages 454–455), l disease and lead poisoning.
(b) (μg/24 h)	130	(80–220)	–	91	
(c) (μg/24 h)	36	6–66	15	92	
Uroporphyrin					
(a) (μg/l)	–	(0–15)	–	86	Values from (a) 25, (b) 9, (c) 72 subjects. Spectrophotometric methods g lower values than fluorometric methods (b)[93]. The excretion of uroporphy is *increased* in some porphyrias[90] (see also pages 454–455).
(b) (μg/24 h)	39	(28–63)	–	91	
(c) (μg/24 h)	12	4–20	4	92	
Bilirubin (mg/l)					
Children	0.9	–	–	95	
Adults	–	(0.02–1.9)	–	96	
Urobilinogen (mg/24 h)	0.36	0.05–2.5	–	97	Values from 46 subjects; the distribution is lognormal. Urobilinogen excret is *decreased* in obstruction of the bile passages, *increased* in liver injury and in vascular haemolysis[97, 98].

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
globin	0	–	–	–	Free haemoglobin (mainly present as methaemoglobin) not bound to the *erythrocytes is present in urine only when the haemoglobin-binding capacity*
bin	0	–	–	–	Myoglobin appears in the urine when the serum level exceeds 0 15–0 2 g/l, for instance after very severe physical effort or serious injuries involving the muscles, an idiopathic paroxysmal form of myoglobinuria is also known[102].
and related compounds					
imidazole carboxle (mg/24 h)	0 4	(0 1–1 0)	–	103	Aminoimidazole carboxamide is an intermediate in the biosynthesis of purine, *the excretion of this substance is increased in vitamin B_{12} deficiency*
	0 90	(0 36–1 58)	–	104	
ne (mg/24 h)	4 9	(2 1–12 0)	–	105	Values determined in the urine of 7 subjects by chromatographic separation For the enzymatic determination of xanthine and hypoxanthine see PETERSEN et al [106]
anthine (mg/24 h). .	6 8	(2 6–12 5)	–	105	
ylhypoxanthine 24 h)	–	(trace)	–	105	
ne (mg/24 h) . ..	0 5	(0–0,7)	–	105	
hylguanine (mg/24 h)	1 2	(0–2 1)	–	105	
hylguanine (mg/24 h)	3 6	(1,0–7,7)	–	105	
ne (mg/24 h) . .	1 5	(0,7–3 6)	–	105	
cid (mg/kg body ght/24 h)					
born, 0–2 days . .	4 8	–	–	2	
ults . .	8 7	–	–	2	
ults (mg/24 h) .	528	80–976	224	107	
oin (mg/24 h).	–	(25–30)	–	110	
idines and related unds					
bosyluracil (pseudodine) (mg/24 h)	46	(24–75)	–	111	Values from 26 healthy subjects on a purine free diet The excretion of pseudouridine is *increased* in gout and also in many patients with leukaemia and psoriasis
ic acid (mg/24 h). ..	1 4	–	–	112	Present in the urine of infants up to 1 5 g/24 h as familial metabolic defect[113]

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...zymes (for definition of the unit U see page 584)

The healthy kidney excretes low-molecular enzymes and their ..., such as amylase and uropepsinogen; if high-molecular ... are excreted at all they include lactate dehydrogenase[1–3], ...artate aminotransferase[2,4], ribonuclease[5], alkaline phosphatase[3,6,7], acid phosphatase[6], arylsulphatases[8], β-glucuro... and aminopeptidase[10]. In renal injury the amounts of th... zymes in the urine are often increased. When determining e... in urine the urinary volume and diuretic state must be tak... account; thus the activity of some enzymes measured per u... ume of urine is higher in antidiuresis than in diuresis[11].

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Amylase (kU/24 h, 37 °C)...	6.03	(2.06–11.8)	–	12	Frequently *increased* in acute pancreatitis.
Uropepsinogen (U/24 h, 37 °C)					
(a) Men	40	2–78	19	13	Values from (a) 21, (b) 18 subjects; substrate haemoglobin. A small ... the pepsinogen secreted in the gastric mucosa enters the blood and is e... by the kidneys; there is, however, little correlation between the uropep... excretion and the pepsinogen content of the gastric juice. Absence of u... sinogen in the urine indicates atrophy of the gastric mucosa.
(b) Women	23	0–51	14	13	

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ıary carbohydrates are present partly in the free form, omponents of glycoproteins, mucopolysaccharides and glycopeptides, partly as glucuronic acid bound to phenols and acids On free sugars in urine see SIDBURY[1].

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
; substances					
) (mg/24 h)	515	(242–845)	–	2	Values from 30 subjects by the NELSON-SOMOGYI method The classical methods of determining 'sugar' are based on the reducing power of certain carbohydrates [illegible] hydrogenase reaction[5]
(mg/l)					
ıorn, 1st week	–	(<250)	–	6	Values (a) by paper chromatography [illegible] tumours
ıorn, 2nd week .	–	(<200)	–	6	
;s (mg/24 h)	72	(16–132)	–	2	
e (mg/l)					
ɔorn, 1st week	–	(<250)	–	6	Values (a) by paper chromatography, (b) from 10 adults on an average diet Infants on a milk diet may excrete up to 400 mg galactose per litre urine, those with galactosaemia up to 10 g per litre[8]
ɔorn, 2nd week	–	(<200)	–	6	
ts .	14	(3–25)	–	7	
: (mg/l)					
ı, 1st week	–	(<700)	–	6	Values by paper chromatography Fructose excretion is *increased* with a high fructose intake, idiopathic fructosuria is also known
n, 2nd week .	–	(<50)	–	6	
(mg/l)					
born, 1st week	–	(<1200)	–	6	Values (a) by paper chromatography, (b) from subjects on a mixed diet No lactose is excreted when the diet is lactose-free Endogenous lactose appears in the urine in late pregnancy and during lactation (up to 500 mg/l)[10]
born, 2nd week .	–	(<100)	–	6	
lts (mg/24 h)	28	(0–91)	–	9	
					Sucrose may appear in the urine after oral intake[11].
(mg/24 h) .	49	(14–111)	–	7	Values from 10 adults on an average diet The excretion of xylose and arabinose is *increased* after consuming fruit[6]
ose (mg/24 h)	38	(12–56)	–	7	
ntoses (mg/24 h)	4 3	0 5–8 1	1 9	12	Values from 15 men The ketopentoses consist *mainly of L-xylulose with traces of ribulose and sedoheptulose* In essential pentosuria 1–5 g L-xylulose per day is excreted independently of the diet[13]
l (mg/l)	–	(35–85)	–	14	Chromatographic studies showed mesoinositol in all samples and scyllitol in 67%
onic acid, total 24 h)					
n	431	271–591	80	15	
men	371	193–549	89	15	
; body weight/24 h)					
wborn, 0–2 weeks	16 4	12 2–20 6	2 12	16	
wborn, 2–7 weeks	8 5	5 54–11 5	1 48	16	
lialysable carbohydrates (mg/24 h)					
es .	72 6	34 4–111	19 1	21	
amines	26 5	14.3–38 7	6 1	21	
ıcid	40 7	25 7–55 7	7 5	21	
ronic acid, children	–	(4 1–14 7)	–	22	
ronic acid, adults	–	(2.7–7.3)	–	22	

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	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Organic acids (mEq/24 h)					
Men	55	–	–	1	Urine contains a large number of aliphatic and aromatic acids; in infan former dominate, in adults – depending on the intake of fruit and vegeta the latter. The aromatic acids are mainly bound to amino acids (page 666 details see the literature[2, 3].
Women	64	–	–	1	
Volatile acids (mg/24 h)	–	(8–50)	–	4	In the main formic acid, a little acetic acid and traces of butyric acid[3].
Formic acid (mg/l)	13	–	–	5	
Adipic acid (mg/24 h)	–	(1.3–2.5)	–	6	
Malic acid (mg/24 h)	5.4	–	–	7	
Succinic acid (mg/24 h)	–	(2–12)	–	8	
Pyruvic acid (mg/24 h)					
(a) Children	5.6	1.9–9.3	1.83	9	Values from (a) 21 children aged 5–10 years, (b) 3 men, (c) 3 women an children aged 3 months to 4 years. *Increased* in non-compensated diabete
(b) Men	9.6	–	–	10	
(c) Women	11.4	–	–	10	
(mg/kg body weight/24 h)					
(d) Children	–	(0.16–0.52)	–	11	
Citric acid					
(a) Adults (mg/24 h)	462	90–834	186	12	Values from (a) 12 adults, (b) children aged 3 months to 4 years. Higher carbohydrate diet than on one rich in proteins, *increased* in treatment oestrogens (whence its fluctuation during the menstrual cycle) and vitami *decreased* in severe muscular activity, acidosis, diabetes, hypoparathyroi and chronic renal insufficiency[7].
(b) Children (mg/kg body weight/24 h)	–	(4–12)	–	11	
Furane-2,5-dicarboxylic acid (mg/24 h)	–	(3–4)	–	13	
Glutaric acid (mg/24 h)	2.5	–	–	15	
α-Ketoglutaric acid (mg/24 h)					
(a) Children	9.3	0.5–18.1	4.4	9	Values from (a) 21 children aged 5–10 years, (b) 3 men, (c) 3 women and children aged 3 months to 4 years. *Decreased* in chronic renal insufficiency
(b) Men	12.0	–	–	10	
(c) Women	18.7	–	–	10	
(d) Children (mg/kg body weight/24 h)	–	(0.5–2.0)	–	11	
ıethylmalonic acid (mg/24 h)	5.8	(0–11.2)	–	14	*Increased* in vitamin B_{12} deficiency.
Lactic acid (mg/24 h)	–	100–600	–	4	Often absent from the urine. *Increased* during severe muscular activity, a following epileptic attacks and in fever.
Glycolic acid (mg/24 h)	42	–	–	16	Values from 15 children, adjusted to a body surface area of 1.73 m^2.
Glyoxylic acid (mg/24 h)	–	(1.4–4.7)	–	17	
Oxalic acid (mg/24 h)					
(a) Children	–	(10–45)	–	18	Values from (a) 25, (b) 18, (c) 60 subjects. In primary hyperoxaluria 100–400 per day is excreted[21].
(b)	31	13–49	9	19	
(c)	–	(9.0–28.5)	–	20	
Ketone bodies (as acetone) (mg/24 h)					
(a)	–	(10–100)	–	22	Values (a) usual in adults; values (b) in young men. The ketone bodies cons of acetoacetic acid, β-hydroxybutyric acid (which must be oxidized bef determination as ketone) and acetone; the proportion of β-hydroxybuty acid increases as the total ketone-body excretion rises. *Increased during fastin* especially when physical work is done at the same time and when the ambi temperature is low; *decreased* in dehydration. It is *pathologically increased* diabetes (up to 50 g/l in poorly adjusted patients), thyreotoxicosis and fev Children are more inclined to hyperketonuria than adults.
(b)	209	(<400)	–	23	
Acetone (mg/l)	0.8	(0.2–2.5)	–	24	

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
nols, aromatic acids	..	...	...	...	The aromatic acids are partly bound to amino acids (page 666), the phenols to glucuronic acid (page 673)
enol (mg/24 h)	10	(8–13)	–	25	
Cresol (mg/24 h)..... ..	87	(64–117)	–	25	
rocatechol (mg/24 h)	5 7	–	–	26	
Methoxy-4-hydroxyphenylglycol (mg/24 h)	3 0	(1 4–4,6)	0 8	27	Values from 18 subjects
Methoxy-4-hydroxyphenylacetic acid (homovanillic acid) (mg/24 h) . .	5 35	3 2–7,6	1 1	28	Values from 15 young adults
anillic acid (mg/24 h) . .	–	(< 5)	–	29	
Methoxy-4-hydroxymandelic acid (mg/24 h) .	3 6	–	–	30	For further data see page 733
Dihydroxyphenylacetic acid (mg/24 h) .	0.7	–	–	31	
Dihydroxymandelic acid (mg/24 h)	0 4	–	–	30	
Homogentisic acid					Excreted in urine in measurable amount only in alkaptonuria (3–5 g/24 h)[32]
m-Hydroxybenzoic acid (mg/24 h)	–	(10–16)	–	33	
p-Hydroxyphenylacetic acid (mg/24 h)	–	(15–31)	–	33	
Lipids					
Non-dialysable lipids (mg/24 h)	15 6	0–31 8	8 1	34	Lipid content of the non-dialysable material in urine (see page 668), consisting of cholesterol, phospholipids and fatty acids, triglycerides are not normally present Lipid excretion is increased in some kidney diseases, particularly the nephrotic syndrome
Cholesterol (mg/24 h)	[illegible]	([illegible]2–3 8)	–	35	Values from 5 subjects
Phospholipids (mg/24 h)	9 5	([illegible]0–13 3)	–	35	Values from 5 subjects

References

[1] Schwab and Kühns, *Die Störungen des Wasser- und Elektrolytstoffwechsels*, Springer Berlin 1959 [illegible]

[2] [illegible]

[15] Thomas and Stalder [illegible]

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Coenzyme Q_{10} (µg/24 h) ...	15.4	(0–58)	–	1	
Thiamine (µg/l)					
(a)	900	(800–2400)	–	2	Values (a) from 31 subjects, using *Ochromonas danica*[2]; values (b) from 2' jects, using *Ochromonas malhamensis*[3]; values (c) on 24 infants during th three days. Except in dietary thiamine deficiency, the urinary thiamir cretion increases linearly with the intake. In thiamine deficiency it falls ra whereas the excretion of thiamine metabolites remains largely constan page 470). In beri-beri 0–14 µg thiamine are excreted daily[5]. Thiamir cretion is increased in diuretic treatment with mercury salts but not thiazides[6].
(b)	–	(110–370)	–	3	
(c) Newborn	96	52–140	22	4	
Riboflavin					
(a) Newborn (µg/l)	219	157–281	31	4	Values from (a) 24 infants during the first three days, (b) 31 children, in of whom values were below 300 µg. Riboflavin excretion varies wit dietary intake (see pages 471–472).
(b) Children, 3–7 years (µg/24 h)	–	(50–650)	–	7	
(c) Adults (µg/24 h)........	–	(150–2000)	–	6	
Vitamin B_6 (µg/24 h)	40	(20–120)	–	8	Determined by means of *Tetrahymena pyriformis*.
(nmol/kg/h)					
Total	–	(0.55–1.24)	–	9	Values from 3 children and 3 adults. The free vitamin was determined b hydrolysis, the total vitamin after hydrolysis, in both cases using *Saccharo carlsbergensis*.
Free	–	(0.08–0.29)	–	9	
Pyridoxic acid	–	(1.7–8.0)	–	9	
Nicotinic acid					
(a) Children (mg/24 h)	2.3	(1.8–2.9)	–	10	Values determined (a) chemically, (b) microbiologically with *Tetrahymena formis*.
(b) Adults (mg/l)	–	(1.16–1.54)	–	3	
1-Methylnicotinamide (mg/24 h)					
(a) Newborn, 4–50 days	1.71	(0.55–4.87)	–	11	Values from (a) 14, (b) 29, (c) 25 subjects. The excretion of this nicotinic metabolite is decreased in pellagra (see page 477).
(b) Children, 6–11 years.....	2.70	(0.77–5.45)	–	12	
(c) Men, under 35 years.....	7.38	(2.85–12.3)	–	13	
(c) Women, under 35 years..	6.05	(2.34–12.7)	–	13	
(c) Men, over 50 years......	3.60	(1.76–10.5)	–	13	
(c) Women, over 50 years ...	3.45	(1.50–9.20)	–	13	
1-Methyl-2-pyridone 5-carboxylamide (mg/24 h)					
(a) Newborn, 4–50 days	1.64	(0.30–6.67)	–	11	Values from (a) 14, (b) 29, (c) 25 subjects. The isomeric compound 1-metl 4-pyridone 5-carboxylamide is also present in urine[14]. The excretion 1-methyl-2-pyridone 5-carboxylamide is increased during pregnancy[15] fluctuates during the menstrual cycle[15,16]; it is pathologically decrease diabetes[17] and pellagra (see page 477).
(b) Children, 6–11 years.....	4.47	(1.55–11.8)	–	12	
(c) Men, under 35 years.....	13.29	(4.44–29.2)	–	13	
(c) Women, under 35 years..	11.14	(4.30–32.2)	–	13	
(c) Men, over 50 years......	6.20	(0.80–21.1)	–	13	
(c) Women, over 50 years ...	12.28	(1.75–29.2)	–	13	
Vitamin B_{12} (ng/24 h)	–	(0–27)	–	19	On a normal diet.
Folic acid (µg/24 h)	4	(2–7)	–	18	On a normal diet.
Biotin (µg/l)	–	(6.26–32.7)	–	3	Values determined with *Ochromonas danica*. Present in the urine in the free fo
Pantothenic acid (mg/l)....	2.90	(0.76–4.1)	–	3	Values determined with *Lactobacillus plantarum*. Present in the urine in the f form.
Ascorbic acid					
(a) Newborn (mg/l)........	45.4	31.8–59.0	6.8	4	Values (a) from 24 infants during the first three days. The values (b) for adu are dependent on the degree of tissue saturation and on the dietary intake (pages 489–490).
(b) Adults (mg/24 h)	–	(10–100)	–	–	

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	Mean	95% range (extreme range in brackets)	*s*	Reference	Remarks
ythrocytes (per ml)	–	0–2500	–	1	On the erythrocyte content of the urine of newborn infants see AAS[3], on that of pregnancy urine see SCHOLZ[4]. The erythrocyte content may be increased in spastic contraction of the renal veins (as for instance in haematuria due to lordotic congestion) as also in various diseases of the kidneys and urinary tract, including kidney stone and bladder stone
r 24 h	130000	–	–	2	
ucocytes (per ml)	–	0–3000	–	1	On the leucocyte content of the urine of newborn infants see AAS[3], on that of pregnancy urine see SCHOLZ[4]. The leucocyte content is increased in all inflammatory renal diseases
en (per h)	46000	(0–220000)	–	5	
omen (per h)	74000	(0–574000)	–	6	
r 24 h	650000	–	–	2	
yaline casts (per 24 h)	2000	–	–	2	73% of all sediments contain no hyaline casts
acteria	.	.	...	...	

eferences

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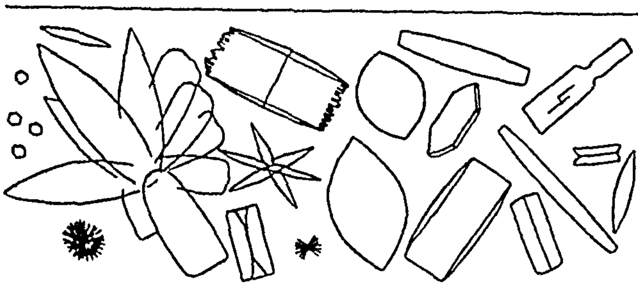
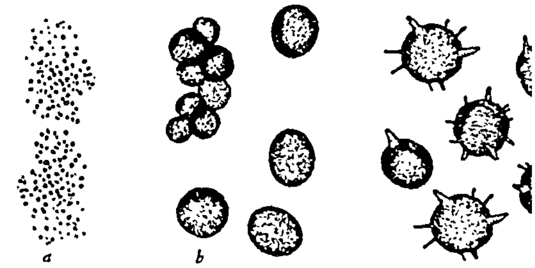
morphous and crystalline chemical sediments

Sediment	Characteristics	Occurrence	Solubility (○ = readily soluble, ● = sparingly soluble) Heating	Alkalis	Mineral acids	Acetic acid	Alcohol	Acetone	Ether
Uric acid	Crystals mostly, but not always, coloured yellow by absorption of urinary pigments	Acid urine	○ (60 °C)	○	●	●	●	●	●
Urates	Calcium, magnesium and potassium urates, mostly amorphous, in concentrated acid urine. Colour and chemical behaviour as for uric acid	Ammonium urate in alkaline urines. All other urates in acid urines	○ (60 °C)	○	●	●	●	●	●
Phosphates									
Calcium phosphate	Rare	Alkaline urine	●	●	○	○	●	●	●
Ammonium magnesium phosphate	Commoner	Alkaline urine	●	●	○	○	●	●	●
Calcium oxalate	Size about that of erythrocytes	Usually in acid urine, also in neutral and weakly alkaline	●	●	○	●	●	●	●
Cystine	Colourless crystals (distinction from uric acid crystals, when of similar form). Must be looked for in fresh urine since cystine is rapidly destroyed by bacteria	Acid urine	●	○ esp. ammonia	○	●	●	●	●
Tyrosine	Often yellow-coloured since they are associated with jaundice. Mostly accompanied by leucine. Occur in acute yellow atrophy of the liver, also in cirrhosis, acute phosphorus poisoning, leukaemia	Acid urine	● (relative)	○ precipitated on neutralization	○ precipitated on neutralization	○	●	●	●
Leucine	See tyrosine. Crystals in urine are impure. Pure leucine crystallizes in hexagonal platelets	Acid urine	○ (relative)	○	○	○	●	●	●
Bilirubin (haematoidin)	Colours any uric acid crystals present and changes their shape	Acid urine	●	○ readily soluble in chloroform	○	○	●	○	●
Indigotin	Rare. Also colours other crystals and thus appears to crystallize in various forms. Pure indigo in urine is amorphous or as *b* in the figure on page 678. Crystallizes from chloroform as *c* in this figure	Alkaline or acid urine	very soluble in chloroform				●	–	○
Cholesterol	Very rare	Acid urine	very soluble in chloroform				●	–	○
Hippuric acid	Very rare		○	○	●	●	●	–	●
Sulphonamides	Easily distinguished from uric acid crystals by solubility in acetone		–	–	–	–	–	○	–

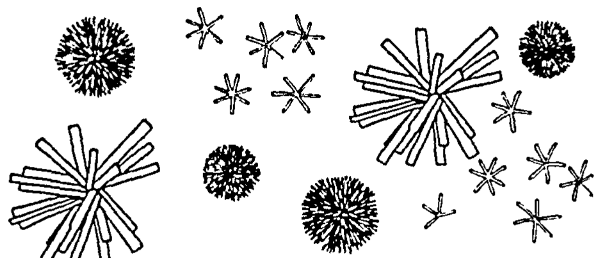
Amorphous and crystalline chemical sediments[1]



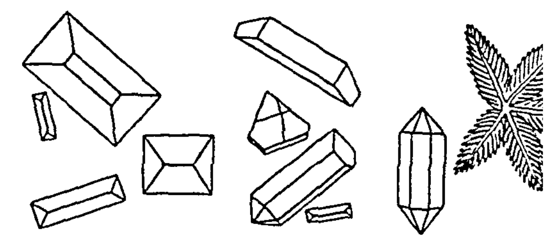
Various crystalline forms of uric acid



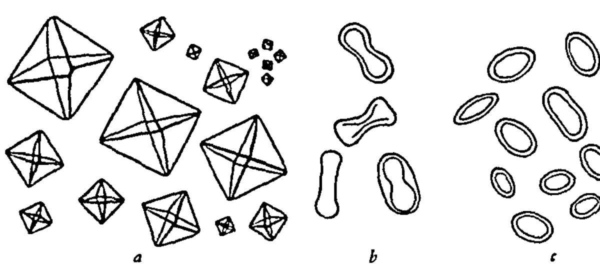
Urates



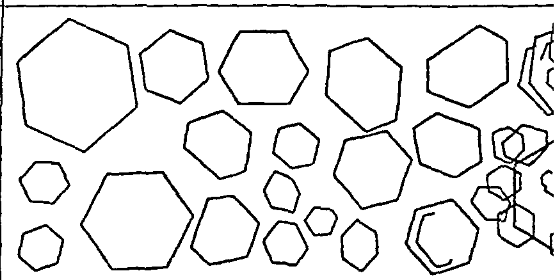
Star-shaped calcium phosphate crystals



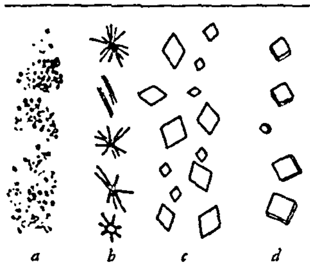
Ammonium magnesium phosphate crystals



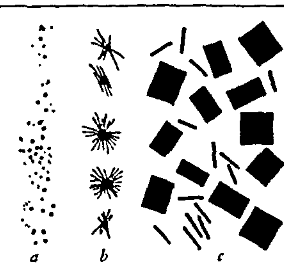
Calcium oxalate crystals



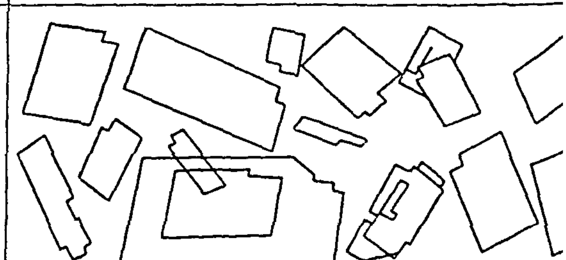
Hexagonal cystine crystals



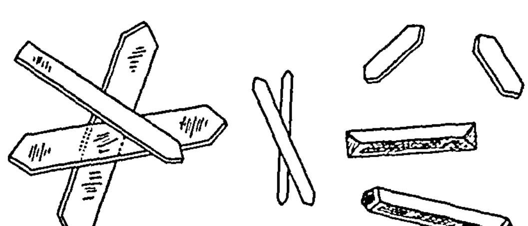
Bilirubin



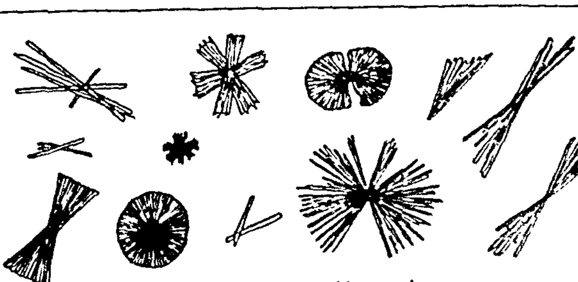
Indigotin



Jagged cholesterol platelets



Hippuric acid



Various sulphonamide crystals

Urates	*a* calcium, magnesium and potassium u mostly amorphous
	b ammonium urate (spherical forms)
	c sodium urate (thorn-apple forms)
Calcium oxalate	*a* octahedra, often flattened (commonest
	b dumb-bell forms
	c ring forms
Bilirubin *reddish brown*	*a* amorphous
	b masses of needles
	c rhombic forms
	d cubic forms
Indigotin *blue*	*a* amorphous } urine
	b masses of needles } urine
	c rectangular platelets from chloroform

[1] From HARRISON, G. A., *Chemical Methods in Clinical Medicine*, 4t Churchill, London, 1957, pages 100 et seq.

Sweat

(For references see page 681)

Sweat is secreted by two kinds of gland, the small, eccrine sweat

pocrine sweat[1], so that unless otherwise stated the data in the

lection, the rate of secretion and the location There is an extensive literature on the composition of eccrine sweat[2–6].

Approximate numbers of sweat glands[3]

Total	2 million
Flexure of elbow	751/cm²
Palm of hand	373/cm²
Chest	155–250/cm²
Buttocks	57/cm²

Eccrine sweat unless otherwise stated	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Physicochemical data					
Appearance	...		.		Eccrine sweat clear, watery, odourless. Apocrine sweat cloudy, viscous, often slightly yellow and fluorescent, sometimes bluish or blackish (chromhidrosis = excessive coloration), sterile apocrine sweat is odourless but rapidly acquires its characteristic smell from bacterial action (bromhidrosis or osmidrosis = development of excessive odour)
Amount (l/24 h)					
(a)	0 3–0 5	–	–	7	(a) Insensible perspiration = macroscopically invisible sweat and transepider-
(b)......	(2–3)	–	–	7	sweating
Specific gravity	–	(1.001–1 008)	–	7	
Freezing-point depression (°C)	–	(0 32–0 37)	–	2	
Surface tension (dyn cm⁻¹)	–	(69–70)	–	12	Measured at 37–38 °C
Water (g/l)	–	(990–995)	–	2	
Dry substance (g/l)	–	(3–10)	–	7	Consists of 50% organic and 50% inorganic matter
pH value	–	(4–6.8)	–	8	Apocrine sweat is about 0 5 pH less acid than eccrine sweat[1], possibly because of its higher ammonia content[13]
Inorganic substances					
Chloride (mEq/l)					
(a) Newborn, 1st day	39	14–64	12 5	14	Measured in pilocarpine sweat from (a) 100, (b) 43, (c) 107, (d) 17, (e) 63 and (f) 31 subjects On the method of determination see Isbott et al [17] On physiological and pathological changes in the chloride content of sweat see under 'Sodium', page 680
(b) Children, 1–12 *months*	12 3	2 5–22 1	4 9	15	
(c) Children, 1–10 years	15 3	0–31 5	8.1	15	
(d) Children, 10–16 years	19 9	1 5–38 3	9.2	15	
(e) Adults, 17–50 years	29 7	0–65 1	17.7	16	
(f) Adults, over 50 years	38 9	34 3–43 5	2.3	16	
Phosphate (*mg/l*)	14	(10–17)	–	18	Measured on 4 children. Data on the phosphate content of sweat vary widely[6,7]
Sulphate (mg/l)	–	(7–190)	–	7	Less than 50% is inorganic sulphate
Bromide (mg/l)	–	(0 182–0 502)	–	19	
Fluoride (mg/l)	–	(0 2–1.8)	–	20	
Iodine (µg/l)	9 5	(5 4–12.2)	–	21	*Increased* in cystic pancreatic fibrosis[22]

Eccrine sweat unless otherwise stated	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Potassium (mEq/l)					
(a) Newborn, 1st day	8	2–14	3	14	Measured in pilocarpine sweat from (a) 100, (b) 43, (c) 107, (d) 17, (e) (f) 6 subjects. The potassium content decreases slightly with increasir of secretion[24]. It is moderately *increased* in cystic pancreatic fibrosis[18], but the change is not as characteristic as that in the sodium or chloride cc
(b) Children, 1–12 months	11.2	4.4–18.0	3.4	15	
(c) Children, 1–10 years	9.6	4.0–15.2	2.8	15	
(d) Children, 10–16 years	8.5	3.7–13.3	2.4	15	
(e) Men, 20–60 years	7.5	4.3–10.7	1.6	23	
(f) Women, 20–60 years	10.0	5.8–14.2	2.1	23	
Sodium (mEq/l)					
(a) Newborn, 1st day	36	10–62	13	14	Measured in pilocarpine sweat from (a) 100, (b) 43, (c) 107, (d) 17, (e) 33, and (g) 21 subjects. The amounts of sodium and chloride in sweat are d dent on many factors[27], such as hereditary disposition, age, season, s collection and diet; they increase as the rate of secretion increases an higher in heat sweat than in pilocarpine sweat[18]. The sodium/chloride is 1.0–1.3[7]. In children and young adults the upper limit of the normal of sodium concentration in heat sweat is reported to be 70–80 mEq/l corresponding figure for chloride being 60–70 mEq/l[11,25,27,28]; durin first days of life this limit is somewhat higher[14]. In cystic pancreatic fib the sodium and chloride contents of sweat almost always exceed these lim values; a less characteristic increase in the sodium content is seen in h functioning of the adrenal cortex[8] (this can be corrected by giving aldosten The sodium and chloride contents are lowered in primary hyperaldost ism[29].
(b) Children, 1–12 months	14.5	5.1–23.9	4.7	15	
(c) Children, 1–10 years	19.5	3.3–35.7	8.1	15	
(d) Children, 10–16 years	29.2	6.0–52.4	11.6	15	
(e) Men, 20–60 years	51.9	9.7–94.1	21.1	23	
(f) Women, 20–60 years	36.5	0–73.9	18.7	23	
(g) Adults, over 65 years	55.5	7.5–104	24.0	26	
Calcium (mEq/l)	–	(0.2–6)	–	7	The calcium content increases with increasing rate of sweat secretion. longed severe sweating may result in serious loss of calcium[30].
Magnesium (mEq/l)	–	(0.03–4)	–	7	
Iron (mg/l)					
Men	1.15	(0.63–1.88)	–	31	About ¼ of the ingested iron is excreted in the sweat when this is free of c the iron content of heat sweat from the arms being 190 µg/l, from the 250 µg/l[33].
Women	1.61	(1.21–2.30)	–	32	
Copper (mg/l)	0.058	–	–	34	
Manganese (mg/l)	0.060	–	–	34	
Zinc (mg/l)	1.15	0.55–1.75	0.30	35	Heat sweat from 10 subjects.
Nitrogenous substances					
Total nitrogen (mg/l)	–	(230–400)	–	5	The nitrogen content of sweat varies widely, published values lying betw 170 and 1960 mg/l, including 50–1500 mg/l urea-N, 10–350 mg/l ammonia and 10–100 mg/l amino-acid-N[7].
Urea (mg/l)	–	(260–1220)	–	5	The urea content of sweat varies widely, published values lying between and 2000 mg/l[8]; in general it is about twice that of the serum[7].
Creatinine (mg/l)	4.6	(2.1–8.4)	–	18	Values from heat sweat of 4 children. Published values range from 0 to 67 mg with a mean of about 4 mg/l[5,7].
Ammonia (mg/l)	–	(60–110)	–	5	The ammonia content of sweat varies widely, published values lying betwe 12 and 425 mg/l[7]; this is partly due to differences in the extent to which u is broken down by bacteria. It is 25–200 times greater than the ammonia co tent of the serum[7].
Amino acids (g/l)					
(a) Children	1.40	1.23–1.58	0.087	18	(a) Calculated as leucine in the pilocarpine sweat of 18 children (in heat swe the mean value is 2.65 g/l). (b) Heat sweat of 4 men. (c) Pilocarpine sweat 151 men and women; the following were quantitatively determined (in ord of decreasing concentration): citrulline, serine, glutamic acid, aspartic aci arginine, threonine, alanine, leucine, glycine, histidine, ornithine, lysine, valin also detected in some samples were phenylalanine, tyrosine, proline, tryp phan, taurine.
(b) Adults	1.38	(0.54–2.59)	–	36	
(c) Adults	0.476	0.27–0.68	0.102	37	
Uric acid (mg/l)	–	(0–15)	–	5	Other studies[38] found no uric acid in sweat.
Urocanic acid (mg/l)	57	1–113	28	18	Pilocarpine sweat of 18 children (mean value in heat sweat 148 mg/l).

Semen

(For references see page 685)

The ejaculate (total semen) is a suspension of spermatozoa in a liquid medium, the seminal plasma. The latter consists of the various secretions of the accessory reproductive organs, namely the testes, epididymides, vasa deferentia, seminal vesicles, prostate and urethral and bulbo-urethral glands. The composition of the total semen depends on the amounts of these individual secretions contained in it. Those of the three principal fractions can be calculated from the content of acid phosphatase, characteristic of the prostate secretion, from the number of spermatozoa, characteristic of the testicular and epididymal secretions, and from the content of fructose, characteristic of the secretion of the seminal vesicles[1]. The method of collection also has some effect on the composition.

In ejaculation a few drops of the urethral and bulbo-urethral gland secretions are first discharged. This is followed by the prostate secretion, usually free of spermatozoa, then by the middle portion of the seminal vesical secretion containing the spermatozoa, and finally by the highly viscous part of the latter secretion[2]. Immediately after ejaculation the semen coagulates as a result of the action of an enzyme from the prostate on a fibrinogen-like protein from the seminal vesicles. Within 15 minutes of ejaculation the semen liquefies as a result of fibrinolysis of the coagulum, a process involving a plasmin-like enzyme from the prostate; this is followed by hydrolysis of the proteins to amino acids and ammonia.

Unless otherwise stated, the data in the following table refer to the liquefied ejaculate. There is an extensive literature on the composition and properties of semen[3-5].

Total semen unless otherwise stated	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Physicochemical data	...	...	...	...	For further data on spermatozoa see page 686.
Appearance	...	...	...	...	The fresh ejaculate is milky, slightly opalescent, and contains glassy, sticky threads as well as sago- and tapioca-like particles. The seminal vesical secretion occasionally contains yellow pigments (flavins).
Volume of the ejaculate (ml)	3.4	0.2–6.6	1.6	6	Values from 1000 measurements after continence of at least 3 days. Very variable in the same subject. Repeated coitus causes a reduction in the volume, long continence an increase (up to 13 ml). 13–33% of the ejaculate volume is from the prostate, 46–80% from the seminal vesicles, about 10% from the epididymides[1,3].
Specific gravity	1.028	(1.020–1.040)	–	5, 7	The specific gravity of the whole ejaculate depends on the spermatozoal content.
	1.035	(1.031–1.039)	–	8	
Prostate secretion	1.022	(1.018–1.027)	–	8	
Seminal vesical secretion	1.037	–	–	8	
Freezing-point depression (°C)					
(a)	–	(0.56–0.58)	–	9	(a) 1 hour, (b) 16 hours after ejaculation.
(b)	–	(0.74–0.78)	–	9	
Osmolality (mosm/kg H_2O)					
Seminal plasma	296	–	–	10	
Spermatozoa	296	–	–	10	
Relative viscosity at 20 °C	6.45	–	–	9	The viscosity of the whole ejaculate is largely dependent on the spermatozoal content; that of the prostate secretion is low, that of the seminal vesical secretion high. The ability to form threads is characteristic of the secretions of the urethral and bulbo-urethral glands[2].
Surface tension (dyn cm^{-1})					
At 20 °C	66	–	–	9	
At 15 °C	–	(52–59.5)	–	11	
Specific conductivity ($S\ cm^{-1}$) at 20 °C	–	(0.0088–0.0108)	–	9	
Water (g/l)	918	(891–944)	–	8	
Prostate secretion	932	(927–936)	–	8	
Seminal vesical secretion	890	–	–	8	
Spermatozoa (g/kg)	830	–	–	10	
Dry substance (g/l)	–	(80–130)	–	8	Consists of about 10% inorganic and 90% organic matter[12].
pH value	7.19	(6.9–7.36)	–	8	Loss of CO_2 on long standing causes semen to become alkaline (pH 7.6–8.0).
Prostate secretion	6.45	(6.3–6.6)	–	8	
Seminal vesical secretion	7.29	–	–	8	
Inorganic substances					
Carbon dioxide (mmol/l)	24	(19.2–33.2)	–	8	
Prostate secretion (mmol/l)	4.2	(3.1–5.4)	–	8	
Spermatozoa (mmol/kg)	10.5	–	–	10	
Chloride (mEq/l)	42.8	(28.3–57.3)	–	8	
Prostate secretion (mEq/l)	38.1	(34.8–46.1)	–	8	
Spermatozoa (mEq/kg)	33	–	–	10	

Semen

(For references see page 685)

Total semen unless otherwise stated	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
hosphorus (g/l)	1.12	–	–	5	
cid-soluble phosphorus ...	0.57	(0 28–0.94)	–	5	The acid-soluble phosphorus of the seminal plasma consists mainly of phosphorylcholine and glycerylphosphorylcholine
Prostate secretion	0 03	(0 02–0.06)	–	13	
Seminal vesical secretion .	0 46	(0 30–0.62)	–	13	
Spermatozoa (g/kg)	1.6	–	–	10	
organic phosphorus	0.11	–	–	5	
ipid phosphorus	0 06	–	–	5	
otassium (mEq/l)	31 3	–	–	14	
	22 9	(17–27.4)	–	8	
rostate secretion	48 3	(28 7–61.4)	–	8	
eminal vesical secretion	17 8	–	–	8	
permatozoa (mEq/kg) . .	35	–	–	10	
Sodium (mEq/l)	117	(100–133)	–	8	
Prostate secretion . . .	153	(149–158)	–	8	
Seminal vesical secretion	103	–	–	8	
Spermatozoa (mEq/kg) ..	110	–	–	10	
Calcium (mEq/l) . .	12 4	(10 6–14 3)	–	8	
Prostate secretion	60.4	(57 4–65 4)	–	8	
Seminal vesical secretion .	7	–	–	1	
Magnesium (mEq/l) .	11 5	–	–	5	
Copper (mg/l)	–	(0 06–0 24)	–	15	
Zinc (mg/g dry substance)					
Seminal plasma	3.1	–	–	16	
Prostate secretion	7 2	–	–	17	
Spermatozoa	2 0	–	–	18	
Nitrogenous substances					
Total nitrogen (g/l)	9 13	(5 60–12.25)	–	8	
Prostate secretion	4 16	(2 95–5 11)	–	8	
Seminal vesical secretion	12.84	(12 33–13 43)	–	8	
Nonprotein nitrogen (g/l)	0 96	(0 73–1 30)	–	8	
Prostate secretion	0 54	(0 30–0 90)	–	8	
Seminal vesical secretion	0 99	–	–	8	
Ammonia (mg/l)	20	–	–	1	Increases on prolonged incubation at 37 °C as a result of progressive decomposition of proteins
Urea (mg/l)					
Seminal plasma	720	–	–	19	
Creatine (mg/l)					
Seminal plasma	170	–	–	20	
Arginine (mg/l)					
Seminal plasma	900	–	–	20	
Amino acids (g/l)					
Seminal plasma	12 6	–	–	21	Total of 19 free and peptide bound amino acids determined by column chromatography All amino acids are present in considerably higher concentrations than in the blood plasma 24 amino acids have been identified in semen by thin layer chromatography[22].
Choline (free) (g/l)	0 70	–	–	23	2 minutes after ejaculation increases to more than 20 g/l 6 hours later as a result of liberation of choline from phosphorylcholine under the action of acid phosphatase
Phosphorylcholine (g/l)	3 06	(2.86–3 80)	–	24	
Glycerylphosphorylcholine (g/l)	0 66	(0.54–0 90)	–	24	

Total semen unless otherwise stated	Mean	(extreme range in brackets)	s	Reference	Remarks
Spermine (g/l)	–	(0.5–3.5)	–	5	Includes about 10% of the diamines spermidine, 1,3-propanediamine and putrescine[25].
Ergothioneine (mg/l)					
Seminal plasma	15	–	–	26	
Seminal vesical secretion	–	(<10)	–	5	
Glutathione (mg/l)					
Seminal plasma	300	–	–	27	
Uric acid (mg/l)	60	–	–	5	
Proteins (g/l) (a)	45.0	(32.9–68.5)	–	8	(a) (Total nitrogen – nonprotein nitrogen) × 6.25; (b) determined gravimetrically; (c) determined by biuret reaction. As immunoelectrophoretic studies [28–30] have shown, the seminal plasma contains various serum proteins (albumin, α_1-globulin, α_2-globulin, transferrin and γG-globulin) as well as organ-specific proteins arising partly from the prostate[29,31], partly from the seminal vesicles[29]. After ejaculation the seminal proteins are rapidly broken down by the action of proteolytic enzymes. The proteins of the spermatozoa consist mainly of nucleoproteins and enzymes.
(b)	58.0	(43.0–77.4)	–	8	
Seminal plasma (c)	–	(18–47)	–	28	
Prostate secretion (a)	21.7	(16.6–29.3)	–	8	
(b)	25.5	(24.6–26.4)	–	8	
Seminal vesical secretion (a)	77.8	–	–	8	
(b)	90.4	–	–	8	
Mucoproteins (g/l)					
Seminal plasma	9	–	–	32	The semen probably also contains other mucoproteins in addition to this fraction adsorbable on benzoic acid.
Sialic acid (g/l)	–	(0.60–1.05)	–	33	Only about 4% of this is dialysable[34], indicating that the sialic acid is a component of the mucoproteins.
Prostate secretion	–	(0.75–1.05)	–	33	
Seminal vesical secretion	–	(<1.3)	–	33	
Deoxyribonucleic acid (pg per spermatozoal nucleus)	2.5	–	–	35	The amount of DNA, an integral component of the chromosomes, in the spermatozoa of men of normal fertility is constant and fairly uniform, whereas in those of men with doubtful fertility it is inconstant and varies widely from one individual to another[35,36]
Enzymes	...	...	...	...	The *spermatozoa* are rich in various enzymes[5] such as cytochromes, succinate dehydrogenase, lactate dehydrogenase, malate dehydrogenase and adenosine triphosphatase. The spermatozoal head contains hyaluronate lyase lightly bound to the cell surface and readily released into the seminal fluid. The *seminal plasma* contains many enzymes; quantitatively determined have been lactate dehydrogenase[37], malate dehydrogenase[37], isocitrate dehydrogenase[37], glutathione reductase[37], aspartate aminotransferase[38], alanine aminotransferase[38], creatine kinase[39], phosphatases[40], α-glucosidase[41], β-galactosidase[42], α-mannosidase[42], β-mannosidase[42], chitobiase[42], β-glucuronidase[42]. The seminal plasma has a high fibrinolytic and proteolytic activity[5] but the enzymes responsible have not been clearly identified.
Alkaline phosphatase (U/l, 37 °C)					
Seminal plasma	–	(18–177)	–	40	For definition of the unit U see page 584.
Acid phosphatase (kU/l, 37 °C)					
Seminal plasma	–	(96–750)	–	40	For definition of the unit U see page 584. The acid phosphatase of semen arises mainly from the prostate. The phosphatase content is fairly constant in different ejaculates of the same individual but may vary widely in different individuals
Prostate secretion					
Boys, 11 years	9	–	–	43	
Boys, 16 years	1540	–	–	43	
Men, 20–40 years	2560	–	–	44	
Men, 40–100 years	660	–	–	44	
Non-nitrogenous substances					
Fructose (g/l)	2.24	(0.91–5.20)	–	5	The fructose content of semen arises mainly from the seminal vesicles and varies widely. None is detectable before puberty or after castration. Values below 1.2 g/l indicate impaired functioning of the interstitial cells of LEYDIG.
Seminal vesical secretion	3.15	(1.7–8.2)	–	7, 5	
Glycogen (g/l)					
Seminal plasma	–	(0.14–5.5)	–	41	
Inositol (g/l)					
Seminal plasma	0.6	–	–	45	

Total semen unless otherwise stated	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Sorbitol (g/l)					
Seminal plasma	0 1	–	–	46	
Pyruvic acid (g/l)					
Seminal plasma	0 29	(0.11–0 56)	–	37	
Citric acid (g/l)	3.76	(0,96–14 3)	–	5	The citric acid content of the semen is a measure of androgenic activity, that of the prostate secretion gradually diminishes after castration
Prostate secretion	–	(4 80–26 9)	–	5	
Seminal vesical secretion	–	(0 15–0 22)	–	5	
Lactic acid (g/l)	0 37	(0 28–0 52)	–	1	
Prostate secretion	0 50	–	–	1	
Lipids					
Total lipids (g/l)					
Seminal plasma	1,88	(1,67–2 06)	–	47	The spermatozoa are rich in various lipids[5] (lipoproteins, triglycerides, free fatty acids, sterols, phospholipids – particularly acetalphosphatides – heptacosan) The lipids of the seminal plasma arise mainly from the prostate and are partly contained in the formed elements of the secretion
Prostate secretion	2 86	(2 60–3 10)	–	47	
Phospholipids (g/l)					
Seminal plasma	0 84	(0 48–1 33)	–	47	
Prostate secretion	1 80	(1 44–2 25)	–	47	
Cholesterol (g/l)					
Seminal plasma	1.03	(0 70–1 20)	–	47	
Prostate secretion	0 80	(0 62–1 05)	–	47	
Prostaglandins (mg/l)					
Seminal plasma					Primary prostaglandins PGE compounds 53 5 mg/l, PGF compounds 8 mg/l, also metabolites of PGE compounds 250 mg/l[48]
Vitamins					
Tocopherol (mg/kg)	9 8	–	–	49	
Vitamin B_{12} (μg/l)					
Seminal plasma	–	(0 30–0 60)	–	50	Determined with *Euglena gracilis* Values are from semen with morphologically normal spermatozoa
Ascorbic acid (mg/l)	43	(18–72)	–	51	The ascorbic acid probably arises from the seminal vesicles rather than from the prostate[52]

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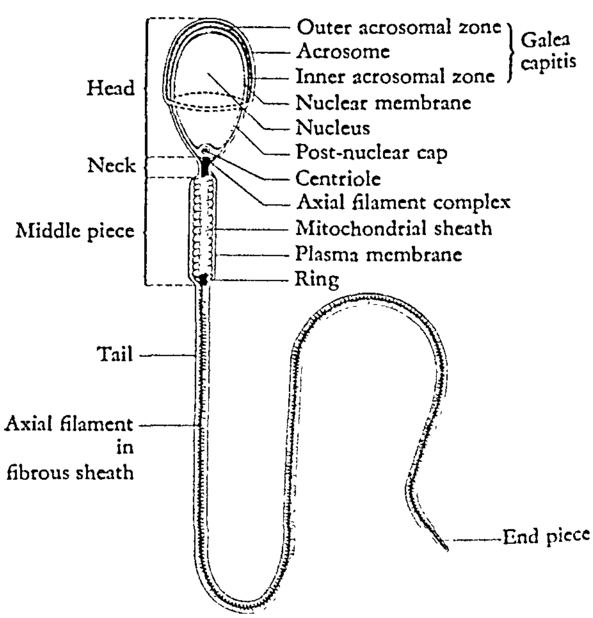
24 Dawson et al , *Biochem J* , 65, 627 (1957),

Spermatozoa

(For other data see pages 682–685)

	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
Number (millions/ml)					
(a)	106.6	0–256	74.5	1	(a) 1000 measurements. The spermatozoal concentration may vary widely in the same individual and is depressed particularly by emotional excitement and physical effort. In some cases long continence also lowers the concentration (but increases the proportion of abnormal forms), as does too high a testicular temperature (cause of testicular degeneration in cryptorchism). Seasonal variations have also been observed (diminished spermatozoal concentration during the warm months) but are not statistically significant. There is no absolute correlation between spermatozoal concentration and fertility or infertility, but in general the spermatozoal content of the ejaculate is lower in infertile men. To this may be added an absolute reduction in the number of spermatozoa due to a smaller volume of the ejaculate, or a dilution of the spermatozoa when the volume of the ejaculate is excessive. The minimum spermatozoal concentration for a fertile semen is regarded as 20–25 million/ml[3].
(b)	–	(28–225)	–	2	
Spermatocrit (ml spermatozoa/l semen)	~10	–	–	4	
Electrophoretic mobility (10^{-5} cm^2 s^{-1} V^{-1})	–	(6.1–8.7)	–	5	At pH 7.8 and 20 °C. The spermatozoa migrate to the anode.
Motility					
In vitro (s mm^{-1})	–	(40–50)	–	6	Normokinetic spermatozoa maintain their motility even 12 hours after ejaculation[6]. In the female genital tract motility is probably maintained for 48 hours. Spermatozoa can be classified according to their motility as follows[11]: 1. Nonmotile (dead), 15%; 2. only slightly motile, 15%; 3. moderately and 4. very motile, together at least 75%. A fertile semen should contain at least 40–60% of normally motile spermatozoa[3].
In vitro (mm min^{-1})	–	(0.3–0.6)	–	7	
In vivo (mm min^{-1})	–	(1.3–2.6)	–	7	
Spermatozoal forms (%)					
Oval	89.8	(66–99)	–	8	A fertile semen should contain at least 60% of morphologically normal spermatozoa and not more than 10% of spermiocytogenic cells[3].
Tapering	3.6	(0–24)	–	8	
Round	1.6	(0–9)	–	8	
Duplicate	1.8	(0–11)	–	8	
Giant and pinhead	0.6	(0–8)	–	8	
Amorphous	2.1	(0–12)	–	8	
Spermatozoal dimensions					
Weight (pg)	37	–	–	9	
Head					
Length (µm)	4.4	(3.3–6.2)	–	9	
Width (µm)	3.2	–	–	9	
Thickness (µm)	2.0	–	–	9	
Volume (µm^3)	6.4	–	–	9	
Middle piece					
Length (µm)	4.0	–	–	9	
Diameter (µm)	1.0	–	–	9	
Volume (µm^3)	3.1	–	–	9	
Tail					
Length (µm)	–	(40–60)	–	9	
Diameter (µm)	–	(0.4–0.7)	–	9	
Volume (µm^3)	–	(4.5–6.8)	–	9	
End piece					
Length (µm)	–	(6–10)	–	9	
Diameter (µm)	0.2	–	–	9	
Volume (µm^3)	0.16	–	–	9	

Diagram of the human spermatozoon[10]



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times must be carefully standardized if valid comparisons a made between subjects[4, 5].

The collection of a 24-hour milk sample means remo child from the breast during that time and emptying the preferably by pump The administrative difficulties involv led some workers to leave the child on one breast while s the contents of the other But even this may mislead, the c tion of milk from the two breasts is not necessarily the sar

There is no escape from the necessity of obtaining com hour samples from both breasts if misleading measuremen be avoided But since this is seldom done, comparisons milk analyses reported in the literature must be made utmost caution.

The composition of breast milk is described in detail by MACY and KELLY[8] and LINTZEL[9]. Data have also been p by the Committee on Nutrition of the American Aca Pediatrics[10]

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In general the yield corresponds to the needs of the infant, ounting to about 850 ml per day for a body weight of 5–6 kg

omposition (see pages 688 and 689)

It is easy to obtain some milk for chemical analysis, and many

ourse of the day[3] For example, the fat content of milk rises

The daily variation in composition mainly concerns the fat content[3, 4]. In one study[3] this was usually lowest at 6 a m, highest

Fatty acids (as percentage by weight of total fatty acids)*

	Mature milk			Colostrum 3rd day			Colostrum 2nd day			Colostrum 1st day			Cow's m	
	Mean	s	Reference	Mean	s	Reference	Mean	s	Reference	Mean	s	Reference	Mean	s
Butyric acid	0.4	–	1	0.3	–	1	0.2	–	1	0.2	–	1	2.7	0.5
Caproic acid	0.1	0.1	2	0.1	–	1	0.1	–	1	0.1	–	1	2.0	0.2
Caprylic acid	0.1	0.2	2	0.1	–	1	0.8	–	1	0.8	–	1	1.2	0.2
Capric acid	0.8	0.4	2	0.9	–	1	3.5	–	1	3.5	–	1	3.2	0.7
Lauric acid	4.7	2.2	2	2.5	1.1	4	1.8	1.2	4	1.1	0.5	4	3.6	1.1
Myristic acid	7.9	1.5	2	5.7	1.7	4	3.6	1.3	4	3.7	1.3	4	11.8	1.5
Palmitic acid	26.7	2.7	2	26.1	3.0	4	26.1	2.7	4	26.9	2.8	4	36.6	4.7
Stearic acid	8.3	1.7	2	5.8	0.9	4	6.5	1.4	4	7.0	1.0	4	8.1	3.2
Arachidic acid	1.3	–	3	–	–	–	–	–	–	–	–	–	1.7	–
Decenoic acid	0.1	–	1	0.1	–	1	0.2	–	1	0.2	–	1	0.3	–
Dodecenoic acid	0.1	–	1	0.1	–	1	0.1	–	1	0.1	–	1	0.2	–
Myristoleic acid	0.24	–	3	0.2	–	1	0.1	–	1	0.1	–	1	1.5	–
Palmitoleic acid	3.4	1.0	2	5.4	0.8	4	4.4	1.5	4	4.3	1.6	4	3.2	0.7
Oleic acid	37.4	3.7	2	43.1	4.5	4	44.2	3.4	4	44.0	4.4	4	17.7	4.6
Eicosenoic acid	0.89	–	1	–	–	–	–	–	–	–	–	–	1.0	–
Linoleic acid	10.6	2.9	2	9.0	1.8	4	11.4	1.7	4	11.9	3.0	4	2.1	0.7
Linolenic acid	0.85	–	3	0.3	–	1	0.3	–	1	0.3	–	1	1.7	0.7
Arachidonic acid	0.57	–	3	1.6	–	1	1.8	–	1	1.8	–	1	0.4	–

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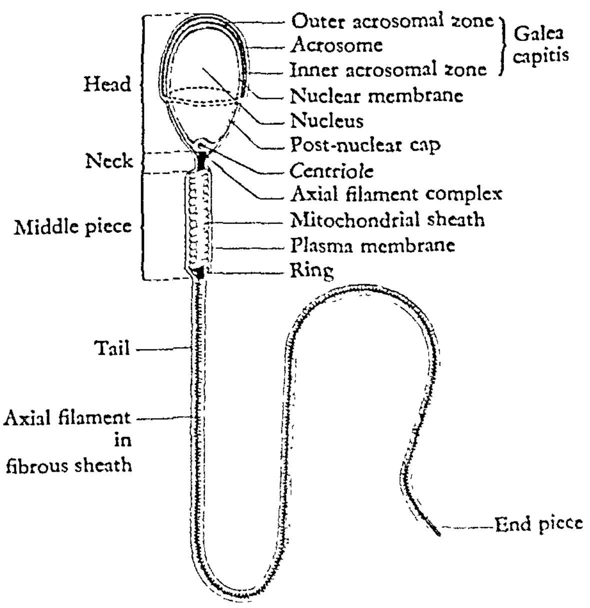
	Mean	95% range (extreme range in brackets)	s	Reference	Remarks
ıber (millions/ml)					
....	106.6	0–256	74.5	1	(a) 1000 measurements. The spermatozoal concentration may vary widely in the same individual and is depressed particularly by emotional excitement and physical effort. In some cases long continence also lowers the concentration (but increases the proportion of abnormal forms), as does too high a testicular temperature (cause of testicular degeneration in cryptorchism). Seasonal variations have also been observed (diminished spermatozoal concentration during the warm months) but are not statistically significant. There is no absolute correlation between spermatozoal concentration and fertility or infertility, but in general the spermatozoal content of the ejaculate is lower in infertile men. To this may be added an absolute reduction in the number of spermatozoa due to a smaller volume of the ejaculate, or a dilution of the spermatozoa when the volume of the ejaculate is excessive. The minimum spermatozoal concentration for a fertile semen is regarded as 20–25 million/ml[3].
....	–	(28–225)	–	2	
matocrit (ml sperma- :oa/l semen)...........	~10	–	–	4	
trophoretic mobility)$^{-5}$ cm^2 s^{-1} V^{-1}).......	–	(6.1–8.7)	–	5	At pH 7.8 and 20 °C. The spermatozoa migrate to the anode.
.lity					
tro (s mm^{-1})..........	–	(40–50)	–	6	Normokinetic spermatozoa maintain their motility even 12 hours after ejaculation[6]. In the female genital tract motility is probably maintained for 48 hours. Spermatozoa can be classified according to their motility as follows[11]: 1. Nonmotile (dead), 15%; 2. only slightly motile, 15%; 3. moderately and 4. very motile, together at least 75%. A fertile semen should contain at least 40–60% of normally motile spermatozoa[3].
tro (mm min^{-1})........	–	(0.3–0.6)	–	7	
vo (mm min^{-1})........	–	(1.3–2.6)	–	7	
matozoal forms (%)					
....	89.8	(66–99)	–	8	A fertile semen should contain at least 60% of morphologically normal spermatozoa and not more than 10% of spermiocytogenic cells[3].
:ring	3.6	(0–24)	–	8	
ıd	1.6	(0–9)	–	8	
licate................	1.8	(0–11)	–	8	
ıt and pinhead	0.6	(0–8)	–	8	
›rphous..............	2.1	(0–12)	–	8	
'matozoal dimensions					
ʒht (pg)..............	37	–	–	9	
ł					
:ngth (µm)...........	4.4	(3.3–6.2)	–	9	
idth (µm)............	3.2	–	–	9	
ıickness (µm)..........	2.0	–	–	9	
ɔlume (µm^3)...........	6.4	–	–	9	
ɗle piece					
:ngth (µm)...........	4.0	–	–	9	
iameter (µm)..........	1.0	–	–	9	
ɔlume (µm^3)...........	3.1	–	–	9	
:ngth (µm)...........	–	(40–60)	–	9	
iameter (µm)..........	–	(0.4–0.7)	–	9	
ɔlume (µm^3)...........	–	(4.5–6.8)	–	9	
piece					
:ngth (µm)...........	–	(6–10)	–	9	
iameter (µm)..........	0.2	–	–	9	
ɔlume (µm^3)...........	0.16	–	–	9	

Diagram of the human spermatozoon[10]



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	Mature milk (15 days to 15 months post partum)				Transitional milk (6–10 days post partum)				Colostrum (first 5 days post partum)				Cow's milk			
	Mean	Experimental range	*s*	Reference	Mean	Experimental range	*s*	Reference	Mean	Experimental range	*s*	Reference	Mean	Experimental range	*s*	Reference
Calories																
kcal/l)	747	446–1192	93	1	735	678–830	36	1	671	588–730	–	1	701	587–876	–	2
MJ/l)	3.127	1.867–4.989	0.389	*Ed*	3.076	2.838–3.474	0.151	*Ed*	2.808	2.461–3.055	–	*Ed*	2.934	2.457–3.666	–	*Ed*
Specific gravity	1.031	1.026–1.037	0.002	1	1.035	1.034–1.036	–	1	1.034	–	–	38	1.031	1.028–1.033	–	3
pH	7.01	6.4–7.6	–	4	–	–	–	–	–	–	–	–	6.6	–	–	5
Solids, total (g/l)	129	103–175	11	1	133	105–156	8	1	128	100–167	13	1	124	119–142	–	3
Ash, total (g/l)	2.02	1.6–2.66	0.18	1	2.67	2.31–3.38	0.32	1	3.08	2.47–3.50	–	1	7.15	6.81–7.71	–	6
Minerals																
(a) *Electropositive elements (mEq/l)*	41	–	–	1	55	–	–	1	68	–	–	1	149	–	–	*Ed*
Sodium (g/l)	0.172	0.064–0.436	0.045	1	0.294	0.192–0.539	0.076	1	0.501	0.265–1.37	0.28	1	0.768	0.392–1.39	–	7
	0.189	0.080–0.350	0.066	39	0.536	0.170–1.21	0.271	39	0.956	0.330–2.24	0.377	39	–	–	–	–
Potassium (g/l)	0.512	0.373–0.635	0.085	1	0.636	0.528–0.769	0.068	1	0.745	0.658–0.870	–	1	1.43	0.38–2.87	–	8
	0.553	0.425–0.735	0.070	39	0.692	0.450–0.910	0.099	39	0.581	0.220–0.790	0.120	39	–	–	–	–
Calcium (g/l)	0.344	0.173–0.609	0.067	1	0.464	0.23–0.628	0.095	1	0.481	0.242–0.656	0.121	1	1.37	0.56–3.81	–	8
	0.271	0.207–0.372	0.030	39	0.320	0.166–0.420	0.045	39	0.261	0.180–0.364	0.026	39	–	–	–	–
Magnesium (g/l)	0.035	0.018–0.057	0.007	1	0.035	0.026–0.054	0.006	1	0.042	0.031–0.082	0.013	1	0.13	0.07–0.22	–	8
(b) *Electronegative elements (mEq/l)*	28	–	–	1	37	–	–	1	40	–	–	1	108	–	–	*Ed*
Phosphorus (g/l)	0.141	0.068–0.268	0.025	1	0.198	0.097–0.317	0.047	1	0.157	0.085–0.251	0.047	1	0.91	0.56–1.12	–	6
Sulphur (g/l)	0.14	0.05–0.30	0.03	1	0.20	0.15–0.23	0.02	1	0.23	0.20–0.26	–	1	0.30	0.24–0.36	–	8
Chlorine (g/l)	0.375	0.088–0.734	0.09	1	0.457	0.305–0.721	0.109	1	0.586	0.435–1.01	–	1	1.08	0.93–1.41	–	8
(c) *Excess electropositive elements (mEq/l)*	13	–	–	1	18	–	–	1	28	–	–	1	41	–	–	*Ed*
(d) *Trace elements*																
Cobalt (µg/l)	trace	–	–	–	–	–	–	–	–	–	–	–	0.6	–	–	9
Iron (mg/l)	0.50	0.20–0.80	–	10	0.59	0.29–1.45	–	40	1.0	–	–	11	0.45	0.25–0.75	–	10
Copper (mg/l)	0.51	–	0.046	11	1.04	–	0.073	11	1.34	–	0.112	11	0.102	–	–	11
Manganese (mg/l)	trace	–	–	12	trace	–	–	13	trace	–	–	13	0.02	0.005–0.067	–	14
Zinc (mg/l)	1.18	0.17–3.02	–	8	3.82	0.39–5.88	–	8	5.59	0.72–9.81	–	8	3.9	1.7–6.6	–	8
Fluorine (mg/l)	0.107	0.0–0.24	–	15	–	–	–	–	0.131	0.0–0.35	–	15	–	0.10–0.28	–	16
Iodine (mg/l)	0.061	0.044–0.093	–	17	–	–	–	–	–	0.045–0.450	–	18	0.116	0.036–1.05	–	17
Selenium (mg/l)	0.021	–	–	41	–	–	–	–	–	–	–	–	*0.04*	*0.005–0.067*	–	41
Protein																
Total (g/l)	10.6	7.3–20	4.6	1	15.9	12.7–18.9	9.8	1	22.9	14.6–68.0	12.6	1	32.46	28.16–36.76	–	19
	–	–	–	–	–	–	–	–	55	14–215	–	20	–	–	–	–
Casein (g/l)	3.7	1.4–6.8	0.8	1	5.1	4.2–5.9	–	1	21	7.3–52	–	20	24.9	21.9–28.0	–	19
Whey protein* (g/l)	7	4–10	–	21	–	–	–	–	–	–	–	–	7	6–10	–	21
'Lactalbumin' (g/l)	3.6	1.4–6.0	1.0	1	7.8	6.9–8.6	–	1	–	–	–	–	2.4	1.4–3.3	–	19
'*Lactoglobulin*' (g/l)	–	–	–	–	5.0	2.1–13.6	–	20	35	4.2–133	–	20	1.7	0.7–3.7	–	19
Blood-serum albumin (g/l)	0.32	0.20–0.47	–	22	0.37	0.26–0.65	–	22	2.5	–	–	42	0.4	–	–	43
Blood-serum immunoglobulin (g/l)	0.09	0.02–0.27	–	22	0.36	0.01–0.96	–	22	1.0	–	–	42	0.8	–	–	43
Amino acids																
Total (g/l)	12.8	9.0–16.0	–	23	9.4	6.0–10.0	–	23	12.0	7.0–40.0	–	23	33.0	27.0–41.0	–	23
Alanine (g/l)	–	0.36–0.42	–	24	–	–	–	–	–	–	–	–	0.75	–	–	44
Arginine (g/l)	0.43	0.28–0.64	0.088	1	0.63	0.48–0.73	0.069	1	0.74	0.62–0.96	–	1	1.4	1.2–1.6	–	25
Aspartic acid (g/l)	–	0.89–0.98	–	24	–	–	–	–	–	–	–	–	1.7	–	–	44
Cystine (g/l)	–	0.23–0.25	–	24	–	–	–	–	–	–	–	–	–	–	–	–
Glutamic acid (g/l)	–	1.89–2.00	–	24	–	–	–	–	–	–	–	–	6.8	–	–	44
Glycine (g/l)	–	0.23–0.24	–	24	–	–	–	–	–	–	–	–	0.11	–	–	44
Histidine (g/l)	0.24	0.12–0.30	0.041	1	0.38	0.29–0.45	0.046	1	0.41	0.35–0.46	–	1	1.2	1.1–1.3	–	25
Isoleucine (g/l)	0.61	0.41–0.92	0.121	1	0.97	0.73–1.21	0.110	1	1.01	0.88–1.15	–	1	2.5	2.1–2.9	–	25
Leucine (g/l)	0.97	0.65–1.47	0.174	1	1.51	1.13–1.97	0.219	1	1.66	1.33–2.14	–	1	3.6	3.2–3.9	–	25
Lysine (g/l)	0.70	0.36–0.93	0.127	1	1.13	0.88–1.48	0.157	1	1.18	0.95–1.41	–	1	2.6	2.3–3.1	–	25
Methionine (g/l)	0.12	0.07–0.16	0.023	1	0.24	0.16–0.34	0.040	1	0.25	0.19–0.36	–	1	0.8	0.6–0.9	–	25
Phenylalanine (g/l)	0.40	0.24–0.58	0.069	1	0.62	0.48–0.71	0.062	1	0.70	0.60–0.84	–	1	1.8	1.5–2.2	–	25
Proline (g/l)	–	0.84–0.94	–	24	–	–	–	–	–	–	–	–	2.5	–	–	44
Serine (g/l)	–	0.47–0.51	–	24	–	–	–	–	–	–	–	–	1.6	–	–	44
Threonine (g/l)	0.52	0.30–0.66	0.085	1	0.78	0.61–0.91	0.079	1	0.85	0.75–1.04	–	1	1.7	1.3–2.2	–	25
Tryptophan (g/l)	0.19	0.14–0.26	0.030	1	0.28	0.23–0.32	0.024	1	0.32	0.25–0.42	–	1	0.6	0.4–0.8	–	25
Tyrosine (g/l)	–	0.46–0.52	–	24	–	–	–	–	–	–	–	–	–	–	–	–
Valine (g/l)	0.73	0.45–1.14	0.155	1	1.05	0.77–1.36	0.122	1	1.17	0.98–1.49	–	1	2.6	2.4–2.8	–	25
Nonprotein nitrogen																
Total (mg/l)																19

Weight gain in pregnancy (per 4-week period)[1]

4-week period of pregnancy	USA 1940[2] lb	USA 1940[2] *kg*	England 1957[3] lb	England 1957[3] *kg*	India 1959[4] lb	India 1959[4] *kg*	Desirable gain[5] lb	Desirable gain[5] *kg*
12–16	3.5	*1.6*	3.1	*1.4*	2.0	*0.9*	2.4	*1.1*
17–20	5.1	*2.3*	4.2	*1.9*	2.4	*1.1*	2.9	*1.3*
21–24	5.1	*2.3*	4.6	*2.1*	3.3	*1.5*	3.3	*1.5*
25–28	4.6	*2.1*	4.2	*1.9*	2.0	*0.9*	4.2	*1.9*
29–32	4.0	*1.8*	3.3	*1.5*	2.0	*0.9*	4.4	*2.*
33–36	4.0	*1.8*	3.5	*1.6*	1.8	*0.8*	4.4	*2.*
37–40	3.3	*1.5*	3.3	*1.5*	0.7	*0.3*	2.6	*1.*

[1] For other values see HYTTEN and LEITCH, *The Physiology of Human Pregnancy*, Blackwell, Oxford, 1964, page 214.
[2] STANDER and PASTORE, *Amer. J. Obstet. Gynec.*, 39, 928 (1940) (2324 subjects).
[3] THOMSON and BILLEWICZ, *Brit. med. J.*, 1, 243 (1957) (2868 subjects).
[4] VENKATACHALAM et al., *Indian J. med. Res.*, 48, 511 (1960) (130 subjects
[5] HÜTER et al., *Geburtsh. u. Frauenheilk.*, 25, 385 (1965). According to thes workers, the gain in weight in healthy women (overall mean 10.2 kg) i independent of age, body size and parity.

Weight gain in pregnancy (per week) from a study on primigravidae made in the Aberdeen Maternity Hospital between 1950 and 195
(P = percentile)

Weeks of pregnancy	Number	P_{10} lb	P_{10} *kg*	P_{25} lb	P_{25} *kg*	P_{50} lb	P_{50} *kg*	P_{75} lb	P_{75} *kg*	P_{90} lb	P_{90} *kg*
		80 %									
				50 %							
13–20	2868	0.42	*0.19*	0.64	*0.29*	0.93	*0.42*	1.19	*0.54*	1.45	*0.6*
20–30	2868	0.60	*0.27*	0.90	*0.41*	1.06	*0.48*	1.32	*0.60*	1.59	*0.7*
30–36	2868	0.35	*0.16*	0.62	*0.28*	0.93	*0.42*	1.28	*0.58*	1.59	*0.7*
36–40	2868	0.04	*0.02*	0.42	*0.19*	0.82	*0.37*	1.24	*0.56*	1.43	*0.6*
20-term (39, 40 or 41 weeks)*..................	486	0.31	*0.14*	0.75	*0.34*	0.97	*0.44*	1.24	*0.56*	1.50	*0.6*

* Group aged 20–29 years, healthy, no major clinical abnormality.

[1] HYTTEN and LEITCH, *The Physiology of Human Pregnancy*, Blackwell, Oxford, 1964, page 214; HYTTEN, F. E., personal communication.

Analysis of weight gain in pregnancy (some values are estimates)[1]

Weeks of pregnancy	Whole body	Foetus	Placenta	Amniotic fluid	Uterus	Breasts	Plasma	Erythrocytes	Extracellular, extravascular water
Total weight gain (g)									
10.........................	650	5	20	30	135	34	100		0
20.........................	4000	300	170	250	585	180	600		0
30.........................	8500	1500	430	600	810	360	1300		0
40.........................	12500	3300	650	800	900	405	1250		1200
Protein storage (g)									
10.........................	35	0.3	2	0	23	9	0		–
20.........................	210	27	16	0.5	100	36	30		–
30.........................	535	160	60	2	139	72	102		–
40.........................	910	435	100	3	154	81	137		–
Fat storage (g)									
10.........................	367	Insignificant	Insignificant	–	0.5	1.4	0.4	–	–
20.........................	1930	2	1	–	2.3	5.4	3.9	–	–
30.........................	3613	80	3	–	3.2	10.8	17.4	–	–
40.........................	4464	430	4	–	3.6	12.2	19.6	–	–
Gain in water (ml)									
40.........................	7000	2343	540	792	743	304	920	163	1195
Gain in extracellular water (ml)									
40.........................	5165	1360	260	792	490	148	920	0	1195
Gain in intracellular water (ml)									
40.........................	1835	983	280	0	253	156	0	163	0
Sodium storage (mEq)									
40.........................	850	280	57	100	78	35	140	5	155
Potassium storage (mEq)									
40.........................	316	154	42	3	49	35	4	24	5
Calcium storage (g)									
40.........................	29.6	28.0	0.65	Insignificant	0.22	0.06	0.12	0.38	0.15

[1] HYTTEN and LEITCH, *The Physiology of Human Pregnancy*, Blackwell, Oxford, 1964.

ıd lipid contents of the plasma before, during and after pregnancy (g/l)[a]

	Number	Albumin		α₂ Globulin		β-Globulin		γ-Globulin		Fibrinogen		Total lipids	
		Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	Mean	s
;nant women	17	38.3	2.7	5.9	0.98	8.8	1.3	14.1	2.4	3.6	0.85	6.2	0.74
t women (weeks)													
....	15	32.6	2.8	6.8	1.3	9.4	1.0	16.1	2.7	3.9	0.7	5.9	1.0
....	28	30.1	3.2	7.0	1.3	10.0	1.8	15.5	2.3	4.5	0.7	5.7	1.2
....	22	28.7	3.8	7.6	1.2	9.6	1.8	15.2	2.8	4.3	0.8	6.1	1.2
....	16	25.3	2.8	7.8	1.5	10.8	1.7	13.7	2.0	4.8	1.0	7.8	1.7
....	22	25.9	3.0	7.4	1.2	11.0	1.5	14.7	2.7	5.1	1.2	8.1	1.4
....	22	23.3	2.6	7.1	1.1	10.6	1.4	14.4	2.4	4.5	0.9	8.7	1.3
....	18	24.8	2.7	6.5	1.0	11.0	1.6	13.3	3.6	4.6	1.0	8.8	1.3
....	15	22.9	2.8	7.3	1.0	10.6	1.5	13.7	1.8	5.0	1.1	9.4	1.8
....	20	23.5	3.0	7.5	1.0	11.7	1.5	14.1	2.4	5.5	1.1	9.5	1.2
....	24	23.0	2.2	7.7	1.1	11.9	1.5	14.1	2.3	5.2	1.5	10.0	1.4
....	21	23.7	2.8	7.3	1.1	11.0	1.4	14.0	2.0	5.5	1.4	10.0	1.9
....	18	24.0	3.3	7.4	1.0	12.0	1.6	13.6	2.8	5.8	1.3	9.9	1.4
rtum													
hours............	15	21.6	2.5	7.1	1.0	10.1	1.7	14.1	2.0	5.0	1.0	8.6	1.1
; hours.........	36	20.3	3.2	7.3	1.0	10.4	1.6	13.3	3.0	5.5	1.9	9.2	2.0
hours...	26	21.0	2.9	7.4	1.2	10.5	1.5	13.9	2.2	5.9	1.4	8.9	1.3
hours....	16	22.1	2.5	7.7	1.1	10.8	1.4	12.3	3.5	5.7	1.6	9.1	1.0
urs to 6½ days ...	40	22.9	3.3	8.5	1.7	11.6	1.5	15.3	3.4	6.1	1.9	9.4	2.0
ays....	52	25.2	2.8	9.1	1.3	12.1	1.6	16.6	2.9	6.0	1.6	9.1	1.7
18 days....... . .	10	26.2	1.7	9.0	2.1	11.6	1.2	17.1	3.6	6.0	2.1	8.3	1.1
) days....	13	33.3	3.0	6.8	1.2	9.1	1.6	17.8	3.7	3.8	0.8	6.6	1.1

o et al., *Amer J Obstet Gynec*, 86, 820 (1963)

ılues in pregnancy[a]

	Plasma volume (ml)	Erythrocyte volume (ml)	Total blood volume (ml)	Body haematocrit (ml/l)	Venous haematocrit (ml/l)	Haemoglobin (calculated) (g/l blood)
gnant women	2600	1400	4000	350	398	131
ıt women (weeks)						
.	3150	1450	4600	315	358	118
.	3750	1550	5200	298	340	112
	3830	1600	5430	295	335	111
.	3600	1650	5250	315	358	118

en and Leitch, *The Physiology of Human Pregnancy*, Blackwell, Oxford, 1964, page 24

l weight of the embryo and foetus[a]

bryonic age	Crown to rump length (mm)	Crown to heel length (mm)	External diameter of chorionic sac (mm)	Weight (g)	Foetal age	Crown to rump length (mm)	Crown to heel length (mm)	External diameter of chorionic sac (mm)
k	0.1*	–	0.2	–	12 weeks	56.0	73.0	[illegible]
ks	0.2*	–	3	–	16 weeks	112.0	157.0	[illegible]
ks	2.0		10	–	20 weeks	160.0	239.0	[illegible]
ks	5.0	–	20	0.02	24 weeks	203.0	296.0	[illegible]
ks	8.0	-	25	–	28 weeks	242.0	355.0	[illegible]
ks	12.0	-	30	–	32 weeks	277.0	409.0	[illegible]
ks	17.0	19.0	40	–	36 weeks	313.0	458.0	[illegible]
ks	23.0	30.0	50	1	Full term (38 weeks).	350.0	500.0	[illegible]

length of the ... Arey, L.B., *Developmental Anatomy*, 7th ed., Saunders, Philadelphia, 1965, page ...

Intrauterine growth*

Number	P_{10}	P_{25} (80 %, 50 %)	P_{50} (80 %, 50 %)	P_{75} (80 %, 50 %)	P_{90}	Weeks of pregnancy	Number	P_{10}	P_{25} (80 %, 50 %)	P_{50} (80 %, 50 %)	P_{75} (80 %, 50 %)	P_{90}
Males: Weight (kg)[1]							Females: Weight (kg)[1]					
13	0.610	0.730	0.830	1.020	1.230	24	11	0.490	0.645	0.760	0.980	1.250
12	0.685	0.790	0.880	1.040	1.260	25	15	0.600	0.740	0.845	1.050	1.295
43	0.760	0.875	0.965	1.110	1.330	26	25	0.700	0.830	0.935	1.125	1.350
38	0.835	0.970	1.080	1.215	1.435	27	34	0.790	0.925	1.035	1.210	1.420
64	0.915	1.075	1.205	1.350	1.570	28	54	0.870	1.020	1.140	1.320	1.530
80	0.995	1.180	1.330	1.495	1.720	29	63	0.945	1.115	1.255	1.455	1.690
61	1.085	1.290	1.465	1.650	1.875	30	48	1.025	1.215	1.380	1.600	1.880
88	1.195	1.415	1.600	1.830	2.050	31	59	1.125	1.330	1.515	1.760	2.100
66	1.320	1.550	1.760	2.045	2.280	32	58	1.250	1.465	1.675	1.970	2.330
62	1.470	1.710	1.970	2.310	2.575	33	56	1.400	1.630	1.875	2.275	2.620
74	1.645	1.920	2.220	2.620	2.920	34	71	1.550	1.825	2.155	2.555	2.920
104	1.875	2.180	2.520	2.885	3.190	35	84	1.730	2.060	2.410	2.795	3.160
118	2.105	2.410	2.745	3.090	3.385	36	84	1.960	2.320	2.630	2.980	3.335
188	2.330	2.625	2.930	3.245	3.540	37	184	2.220	2.520	2.800	3.120	3.450
354	2.505	2.795	3.080	3.380	3.665	38	282	2.405	2.680	2.940	3.235	3.545
504	2.630	2.915	3.200	3.505	3.780	39	506	2.540	2.810	3.060	3.340	3.640
576	2.700	2.995	3.290	3.610	3.880	40	588	2.630	2.905	3.160	3.440	3.720
312	2.735	3.035	3.330	3.670	3.940	41	320	2.660	2.950	3.210	3.520	3.795
164	2.730	3.005	3.310	3.660	3.995	42	172	2.630	2.940	3.210	3.550	3.840
Males and females: Length (cm)[2]							Males and females: Head circumference (cm)[2]					
30	30.8	32.9	35.5	37.5	39.9	26	24	22.4	23.6	25.2	26.6	28.5
21	31.8	34.1	36.6	38.6	41.0	27	20	23.2	24.4	25.8	27.2	28.9
46	33.0	35.5	37.8	39.8	42.2	28	40	24.3	25.4	26.7	28.0	29.4
53	34.4	36.8	39.0	40.9	43.1	29	49	25.3	26.4	27.6	28.8	30.2
47	36.1	38.3	40.3	42.2	44.5	30	49	26.2	27.4	28.6	29.7	31.1
54	37.5	39.7	41.6	43.5	45.9	31	53	26.9	28.2	29.6	30.5	31.9
62	38.8	41.1	43.2	45.0	47.2	32	58	27.6	29.0	30.4	31.4	32.7
69	39.9	42.3	44.7	46.2	48.4	33	65	28.4	29.8	31.2	32.1	33.4
111	41.0	43.4	45.8	47.3	49.4	34	103	29.2	30.6	31.9	32.9	34.0
149	42.0	44.6	46.7	48.1	50.2	35	149	30.0	31.3	32.5	33.4	34.5
189	43.1	45.6	47.4	48.8	50.9	36	186	30.6	31.8	32.9	33.8	34.9
345	44.1	46.5	48.0	49.3	51.3	37	353	31.1	32.3	33.2	34.1	35.2
595	44.9	47.1	48.4	49.8	51.7	38	611	31.4	32.5	33.4	34.3	35.4
957	45.5	47.6	48.8	50.1	52.0	39	961	31.6	32.8	33.7	34.6	35.7
1084	45.8	47.9	49.2	50.5	52.3	40	1097	31.8	33.0	34.0	34.8	35.9
589	46.0	48.1	49.5	50.8	52.6	41	587	32.0	33.2	34.2	35.0	36.0
315	46.2	48.2	49.7	51.0	52.8	42	315	32.1	33.4	34.3	35.1	36.2

* Live births in the Colorado General Hospital, Denver, between 1948 and 1961 (P = percentile).

[1] LUBCHENCO et al., *Pediatrics*, 32, 793 (1963).
[2] LUBCHENCO et al., *Pediatrics*, 37, 403 (1966).

Weight loss during the first days of life[1]

	Average weight at birth (g)	Weight loss as per cent of birth weight: 3rd day Mean	3rd day s	5th day Mean	5th day s	7th day Mean	7th day s
Normal birth	3465	7.22	2.52	7.29	3.14	5.72	3.29
Caesarean section with labour pains..	3580	7.19	2.09	7.65	2.83	6.06	3.31
Caesarean section without labour pains	3550	7.27	2.33	7.97	2.17	7.66	3.34

[1] Births in the Helsinki Women's Hospital between 1947 and 1952; from FURUHJELM, U., *Etud. néo-natal.*, 3, 93 (1954).

Mean weekly weight gains (in ounces and *grammes*) of infants with low birth weight[1]

Age in months	Boys, birth weight 2–<3 lb *0.91–<1.36 kg*	Boys 3–<4 lb *1.36–<1.81 kg*	Boys 4–<5 lb *1.81–<2.27 kg*	Boys 5–<6 lb *2.27–<2.72 kg*	Boys full term	Girls, birth weight 2–<3 lb *0.91–<1.36 kg*	Girls 3–<4 lb *1.36–<1.81 kg*	Girls 4–<5 lb *1.81–<2.27 kg*	Girls 5–<6 lb *2.27–<2.72 kg*	Girls full term
0–1......	4.0 *113*	4.9 *139*	5.6 *159*	5.8 *164*	– –	4.0 *113*	4.9 *139*	5.6 *159*	5.1 *145*	– –
1–3......	7.2 *204*	7.8 *221*	8.3 *235*	8.5 *241*	8.3 *235*	6.6 *187*	6.9 *196*	6.8 *193*	7.0 *198*	7.1 *201*
3–6......	8.1 *230*	7.5 *213*	6.7 *190*	6.1 *173*	5.3 *150*	7.1 *201*	6.6 *187*	6.3 *179*	6.1 *173*	5.1 *145*
6–9......	5.1 *145*	4.7 *133*	4.4 *125*	4.0 *113*	3.7 *105*	5.5 *156*	5.1 *145*	5.0 *142*	4.6 *130*	3.6 *102*
9–12.....	3.5 *99*	3.2 *91*	3.0 *85*	2.9 *82*	2.5 *71*	3.7 *105*	3.2 *91*	2.8 *79*	2.4 *68*	2.4 *68*

[1] LEVIN et al., *Weight Gains, Serum Protein Levels and Health of Breast Fed and Artificially Fed Infants*, Medical Research Council, Special Report Series, No. 296, HMSO, London, 1959, pages 102 and 104.

Normal Measurements During Growth – Birth to 6 Months[1]

Weight in pounds and *kilogrammes*; other measurements in inches and *centimetres* (*P* = percentile)

Boys

	Number	P_{3}	P_{10} (80%)	P_{25} (50%)	P_{50}	P_{75} (50%)	P_{90} (80%)	P_{97}
At birth								
Weight		5.7 / *2.60*	6.2 / *2.80*	6.8 / *3.10*	7.5 / *3.40*	8.2 / *3.70*	8.6 / *3.90*	8.8 / *4.01*
Length		18.5 / *47.0*	19.3 / *49.0*	19.3 / *49.0*	19.9 / *50.5*	20.5 / *52.0*	20.7 / *52.5*	20.9 / *53.0*
1 month								
Weight		7.5 / *3.42*	7.9 / *3.57*	8.2 / *3.72*	8.9 / *4.04*	9.5 / *4.29*	10.1 / *4.58*	10.4 / *4.73*
Length		20.5 / *52.0*	20.7 / *52.5*	20.9 / *53.2*	21.5 / *54.5*	22.0 / *55.8*	22.4 / *56.8*	22.4 / *57.0*
Sitting height		13.3 / *33.7*	13.4 / *34.0*	13.8 / *35.0*	14.2 / *36.0*	14.4 / *36.5*	14.6 / *37.0*	14.8 / *37.7*
Head circ		13.9 / *35.3*	14.2 / *36.0*	14.4 / *36.5*	14.8 / *37.5*	15.0 / *38.0*	15.4 / *39.0*	15.4 / *39.0*
2 months								
Weight		9.4 / *4.27*	9.8 / *4.43*	10.4 / *4.73*	11.0 / *4.98*	11.8 / *5.34*	12.4 / *5.64*	12.5 / *5.69*
Length		21.9 / *55.5*	22.0 / *56.0*	22.4 / *57.0*	22.8 / *58.0*	23.2 / *59.0*	23.4 / *59.5*	23.8 / *60.4*
Sitting height		14.0 / *35.5*	14.4 / *36.5*	14.6 / *37.0*	15.0 / *38.0*	15.4 / *39.0*	15.6 / *39.5*	15.7 / *40.0*
Head circ		14.8 / *37.5*	15.0 / *38.0*	15.2 / *38.5*	15.4 / *39.0*	15.7 / *40.0*	15.9 / *40.5*	16.0 / *40.7*
3 months								
Weight		11.4 / *5.18*	11.9 / *5.40*	12.6 / *5.73*	13.2 / *6.00*	13.9 / *6.32*	14.7 / *6.66*	15.2 / *6.90*
Length		23.0 / *58.3*	23.2 / *59.0*	23.8 / *60.5*	24.0 / *61.0*	24.6 / *62.5*	24.9 / *63.2*	25.0 / *63.6*
Sitting height		15.0 / *38.0*	15.2 / *38.5*	15.6 / *39.5*	15.9 / *40.5*	16.1 / *41.0*	16.3 / *41.5*	16.5 / *42.0*
Head circ		15.4 / *39.0*	15.6 / *39.5*	15.7 / *40.0*	15.9 / *40.5*	16.3 / *41.5*	16.5 / *42.0*	16.7 / *42.5*
Chest circ		15.0 / *38.0*	15.2 / *38.6*	15.6 / *39.7*	16.1 / *41.0*	16.2 / *41.2*	16.5 / *42.0*	16.5 / *42.0*
4 months								
Weight		12.8 / *5.82*	13.0 / *5.91*	14.0 / *6.35*	15.1 / *6.84*	15.9 / *7.23*	16.5 / *7.49*	17.1 / *7.77*
Length		23.7 / *60.1*	24.1 / *61.3*	25.0 / *63.5*	25.4 / *64.5*	25.8 / *65.5*	26.1 / *66.3*	26.4 / *67.0*
Sitting height		15.6 / *39.5*	15.7 / *40.0*	16.1 / *41.0*	16.5 / *42.0*	16.9 / *43.0*	17.1 / *43.5*	17.3 / *44.0*
Head circ		15.7 / *40.0*	15.9 / *40.5*	16.1 / *41.0*	16.3 / *41.5*	16.7 / *42.5*	16.9 / *43.0*	17.1 / *43.5*
5 months								
Weight	61	13.6 / *6.19*	14.4 / *6.52*	15.2 / *6.91*	16.2 / *7.37*	17.4 / *7.90*	17.7 / *8.04*	18.3 / *8.29*
Length	61	24.6 / *62.5*	25.0 / *63.5*	25.8 / *65.5*	26.2 / *66.5*	26.6 / *67.5*	27.1 / *68.9*	27.2 / *69.0*
Sitting height	58	16.1 / *40.9*	16.3 / *41.5*	16.6 / *42.2*	17.1 / *43.5*	17.3 / *44.0*	17.6 / *44.6*	17.7 / *45.0*
Head circ.	57	16.1 / *41.0*	16.1 / *41.0*	16.5 / *42.0*	16.9 / *43.0*	17.1 / *43.5*	17.3 / *44.0*	17.5 / *44.5*
6 months								
Weight	73	14.9 / *6.74*	15.4 / *7.00*	16.5 / *7.48*	17.9 / *8.12*	18.7 / *8.49*	19.3 / *8.77*	19.8 / *8.98*
Length	73	25.2 / *64.1*	25.6 / *65.1*	26.4 / *67.1*	27.0 / *68.5*	27.4 / *69.5*	28.1 / *71.3*	28.2 / *71.6*
Sitting height	73	16.5 / *41.8*	16.7 / *42.5*	17.1 / *43.5*	17.5 / *44.5*	17.7 / *45.0*	18.1 / *46.0*	18.3 / *46.5*
Head circ	73	16.5 / *41.8*	16.7 / *42.5*	16.9 / *43.0*	17.1 / *43.5*	17.5 / *44.5*	17.7 / *45.0*	17.9 / *45.5*
Chest circ	24	16.5 / *42.0*	16.7 / *42.4*	16.9 / *43.0*	17.3 / *44.0*	17.7 / *45.0*	18.1 / *46.0*	18.1 / *46.0*

Girls

	Number	P_{3}	P_{10} (80%)	P_{25} (50%)	P_{50}	P_{75} (50%)	P_{90} (80%)	P_{97}
At birth								
Weight	121	5.8 / *2.64*	6.0 / *2.70*	6.5 / *2.95*	7.1 / *3.20*	7.8 / *3.53*	8.7 / *3.96*	9.0 / *4.06*
Length	118	18.5 / *47.0*	18.5 / *47.0*	19.2 / *48.7*	19.5 / *49.5*	20.1 / *51.0*	20.5 / *52.0*	20.9 / *53.0*
1 month								
Weight	48	7.4 / *3.36*	7.6 / *3.44*	8.0 / *3.63*	8.5 / *3.86*	9.0 / *4.08*	9.7 / *4.42*	9.9 / *4.50*
Length	49	20.0 / *50.7*	20.2 / *51.4*	20.7 / *52.5*	20.9 / *53.2*	21.5 / *54.5*	21.9 / *55.5*	22.3 / *56.7*
Sitting height	42	13.0 / *33.0*	13.2 / *33.5*	13.5 / *34.2*	13.8 / *35.0*	14.2 / *36.0*	14.5 / *36.9*	14.9 / *37.9*
Head circ	44	13.5 / *34.2*	13.9 / *35.3*	14.2 / *36.0*	14.4 / *36.5*	14.6 / *37.0*	15.0 / *38.1*	15.1 / *38.4*
2 months								
Weight	57	9.0 / *4.07*	9.2 / *4.19*	9.9 / *4.48*	10.5 / *4.75*	11.1 / *5.02*	11.7 / *5.31*	12.1 / *5.50*
Length	56	21.2 / *53.9*	21.5 / *54.5*	22.0 / *56.0*	22.2 / *56.5*	22.6 / *57.5*	23.0 / *58.5*	23.4 / *59.5*
Sitting height	50	13.9 / *35.2*	14.0 / *35.5*	14.4 / *36.5*	14.8 / *37.5*	15.0 / *38.0*	15.2 / *38.5*	15.4 / *39.0*
Head circ	53	14.3 / *36.3*	14.6 / *37.0*	14.8 / *37.5*	15.2 / *38.5*	15.4 / *39.0*	15.6 / *39.5*	15.7 / *40.0*
3 months								
Weight	60	10.6 / *4.80*	10.8 / *4.89*	11.5 / *5.20*	12.2 / *5.53*	13.1 / *5.95*	13.7 / *6.23*	14.2 / *6.46*
Length	58	22.6 / *57.4*	22.8 / *58.0*	23.0 / *58.5*	23.4 / *59.5*	23.8 / *60.5*	24.3 / *61.6*	24.8 / *63.0*
Sitting height	55	14.8 / *37.5*	14.8 / *37.5*	15.2 / *38.5*	15.4 / *39.0*	15.7 / *40.0*	15.9 / *40.5*	16.2 / *41.1*
Head circ	55	15.0 / *38.0*	15.0 / *38.2*	15.4 / *39.0*	15.7 / *40.0*	15.9 / *40.5*	16.1 / *41.0*	16.2 / *41.2*
Chest circ	16	14.7 / *37.4*	15.0 / *38.0*	15.2 / *38.5*	15.7 / *40.0*	15.9 / *40.5*	16.1 / *41.0*	16.2 / *41.2*
4 months								
Weight	58	11.5 / *5.22*	11.9 / *5.42*	12.7 / *5.77*	13.8 / *6.24*	15.1 / *6.85*	15.7 / *7.13*	16.4 / *7.43*
Length	58	23.4 / *59.5*	23.6 / *60.0*	23.8 / *60.5*	24.4 / *62.0*	25.0 / *63.5*	25.4 / *64.5*	25.4 / *64.6*
Sitting height	56	15.0 / *38.0*	15.4 / *39.0*	15.7 / *40.0*	15.9 / *40.5*	16.3 / *41.5*	16.5 / *42.0*	16.6 / *42.1*
Head circ	55	15.4 / *39.0*	15.4 / *39.2*	15.7 / *40.0*	16.1 / *41.0*	16.4 / *41.6*	16.7 / *42.5*	16.9 / *43.0*
5 months								
Weight	62	13.2 / *6.00*	13.3 / *6.05*	14.3 / *6.50*	15.4 / *7.00*	16.3 / *7.40*	17.0 / *7.71*	17.3 / *7.86*
Length	61	24.4 / *62.0*	24.6 / *62.5*	25.0 / *63.5*	25.2 / *64.0*	25.8 / *65.5*	26.2 / *66.5*	26.4 / *67.0*
Sitting height	59	15.9 / *40.5*	15.9 / *40.5*	16.1 / *41.0*	16.5 / *42.0*	16.7 / *42.5*	17.1 / *43.5*	17.3 / *44.0*
Head circ.	59	15.7 / *40.0*	15.9 / *40.5*	16.1 / *41.0*	16.5 / *42.0*	16.7 / *42.5*	16.9 / *43.0*	17.3 / *44.0*
6 months								
Weight	74	14.0 / *6.34*	14.4 / *6.53*	15.3 / *6.92*	16.5 / *7.48*	17.5 / *7.93*	18.2 / *8.27*	19.0 / *8.62*
Length	74	25.0 / *63.5*	25.2 / *64.0*	25.6 / *65.0*	26.2 / *66.5*	26.6 / *67.5*	27.3 / *69.3*	27.4 / *69.6*
Sitting height	73	16.1 / *41.0*	16.3 / *41.5*	16.7 / *42.5*	16.9 / *43.0*	17.3 / *44.0*	17.6 / *41.7*	17.7 / *45.0*
Head circ	73	16.1 / *40.8*	16.3 / *41.5*	16.5 / *42.0*	16.9 / *43.0*	17.1 / *43.5*	17.3 / *44.0*	17.5 / *44.5*
Chest circ	23	15.5 / *39.3*	16.1 / *41.0*	16.5 / *41.8*	16.9 / *43.0*	17.3 / *44.0*	17.6 / *44.7*	17.7 / *45.0*

[1] HEIMENDINGER, J., *Helv. paed. Acta*, 19, 406 (1964). From measurements made in the period 1957–1962 in northwest Switzerland on 341 boys and 326 girls mostly of German Swiss descent

Normal Measurements During Growth – 7 Months to 12 Months[1]

Weight in pounds and *kilogrammes*; other measurements in inches and *centimetres* (P = percentile)

Boys Number	P_{05}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{95}		Girls Number	P_{05}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{95}
				50%									50%			
		80%									80%					
	90%									90%						
								7 months								
50	15.9 *7.19*	16.3 *7.41*	17.3 *7.86*	18.4 *8.36*	19.5 *8.85*	19.9 *9.02*	20.2 *9.15*	Weight	47	14.8 *6.72*	15.1 *6.87*	16.0 *7.28*	17.4 *7.87*	18.3 *8.31*	19.5 *8.86*	20.1 *9.13*
49	25.7 *65.2*	26.2 *66.5*	27.0 *68.7*	27.6 *70.0*	28.0 *71.0*	28.3 *72.0*	28.8 *73.2*	Length	47	25.6 *65.1*	25.8 *65.5*	26.2 *66.5*	26.8 *68.0*	27.4 *69.5*	27.8 *70.5*	28.0 *71.0*
48	16.9 *43.0*	17.1 *43.5*	17.5 *44.5*	17.7 *45.0*	18.1 *46.0*	18.5 *47.0*	18.6 *47.3*	Sitting height	46	16.6 *42.1*	16.9 *42.8*	17.1 *43.5*	17.3 *44.0*	17.7 *45.0*	18.0 *45.7*	18.4 *46.8*
48	16.7 *42.5*	16.9 *42.9*	17.1 *43.5*	17.3 *44.0*	17.7 *45.0*	18.0 *45.6*	18.1 *46.0*	Head circ.	46	16.3 *41.5*	16.5 *42.0*	16.9 *43.0*	17.1 *43.5*	17.5 *44.5*	17.7 *45.0*	17.8 *45.3*
20	16.5 *42.0*	16.7 *42.5*	16.9 *43.0*	17.3 *44.0*	17.7 *45.0*	18.1 *46.0*	18.1 *46.0*	Chest circ.	16	15.7 *39.8*	16.1 *41.0*	16.7 *42.5*	17.3 *44.0*	17.7 *45.0*	17.7 *45.0*	17.8 *45.2*
								8 months								
59	16.8 *7.63*	17.8 *8.06*	18.4 *8.35*	19.8 *8.97*	20.7 *9.37*	21.3 *9.66*	21.8 *9.88*	Weight	56	15.7 *7.10*	15.8 *7.16*	16.7 *7.56*	18.2 *8.24*	19.4 *8.78*	20.5 *9.30*	21.5 *9.74*
59	26.3 *66.9*	26.8 *68.0*	27.8 *70.5*	28.1 *71.5*	28.6 *72.6*	29.1 *74.0*	29.3 *74.5*	Length	55	26.2 *66.5*	26.4 *67.0*	26.8 *68.0*	27.4 *69.5*	28.0 *71.0*	28.4 *72.2*	28.7 *73.0*
57	17.1 *43.4*	17.3 *44.0*	17.7 *45.0*	18.1 *46.0*	18.5 *47.0*	18.7 *47.5*	18.9 *48.0*	Sitting height	55	16.9 *42.8*	17.1 *43.5*	17.5 *44.5*	17.7 *45.0*	18.1 *46.0*	18.4 *46.7*	18.5 *47.0*
56	16.9 *43.0*	16.9 *43.0*	17.5 *44.5*	17.7 *45.0*	18.1 *46.0*	18.3 *46.5*	18.3 *46.5*	Head circ.	55	16.5 *42.0*	16.8 *42.7*	17.1 *43.5*	17.5 *44.5*	17.7 *45.0*	18.1 *46.0*	18.1 *46.0*
19	16.9 *42.8*	16.9 *43.0*	17.3 *44.0*	17.7 *45.0*	18.1 *46.0*	18.3 *46.5*	18.5 *46.9*	Chest circ.	20	16.7 *42.5*	16.7 *42.5*	16.9 *43.0*	17.7 *45.0*	18.1 *46.0*	18.5 *47.0*	18.7 *47.5*
								9 months								
66	17.6 *8.00*	18.3 *8.30*	19.2 *8.71*	20.7 *9.37*	21.6 *9.82*	22.8 *10.36*	22.9 *10.40*	Weight	72	16.1 *7.30*	16.8 *7.62*	17.4 *7.90*	18.9 *8.58*	20.3 *9.23*	21.4 *9.71*	21.8 *9.88*
66	27.1 *68.8*	28.0 *71.0*	28.3 *72.0*	28.7 *73.0*	29.1 *74.0*	29.5 *75.0*	29.8 *75.8*	Length	72	26.7 *67.9*	27.0 *68.6*	27.4 *69.5*	28.0 *71.0*	28.3 *72.0*	28.9 *73.5*	29.1 *74.0*
63	17.5 *44.5*	17.7 *45.0*	18.1 *46.0*	18.3 *46.5*	18.7 *47.5*	19.0 *48.3*	19.3 *49.0*	Sitting height	72	17.0 *43.3*	17.3 *44.0*	17.7 *45.0*	17.9 *45.5*	18.3 *46.5*	18.5 *47.0*	18.8 *47.7*
65	17.3 *44.0*	17.3 *44.0*	17.7 *45.0*	18.1 *46.0*	18.3 *46.5*	18.5 *47.0*	18.7 *47.5*	Head circ.	72	16.9 *42.8*	16.9 *43.0*	17.3 *44.0*	17.7 *45.0*	17.9 *45.5*	18.1 *46.0*	18.3 *46.5*
24	17.2 *43.6*	17.3 *44.0*	17.3 *44.0*	17.9 *45.5*	18.5 *47.0*	18.5 *47.0*	18.8 *47.8*	Chest circ.	26	16.7 *42.5*	16.9 *43.0*	17.3 *44.0*	17.7 *45.0*	18.2 *46.2*	18.6 *47.2*	18.8 *47.8*
								10 months								
36	17.6 *8.00*	18.3 *8.30*	19.5 *8.85*	20.7 *9.40*	21.6 *9.82*	22.9 *10.41*	23.5 *10.66*	Weight	36	16.8 *7.60*	17.3 *7.84*	18.3 *8.30*	19.3 *8.74*	20.4 *9.25*	21.8 *9.90*	22.2 *10.07*
36	27.5 *69.9*	28.0 *71.0*	28.5 *72.5*	28.9 *73.5*	29.3 *74.5*	30.1 *76.4*	30.4 *77.1*	Length	36	27.0 *68.5*	27.2 *69.1*	27.8 *70.5*	28.3 *72.0*	28.7 *73.0*	29.1 *74.0*	29.4 *74.7*
34	17.7 *45.0*	17.7 *45.0*	18.1 *46.0*	18.3 *46.5*	18.7 *47.5*	19.1 *48.5*	19.3 *49.0*	Sitting height	36	17.2 *43.8*	17.4 *44.3*	17.7 *45.0*	18.1 *46.0*	18.5 *47.0*	18.6 *47.2*	18.9 *48.0*
36	17.3 *44.0*	17.3 *44.0*	17.7 *45.0*	18.1 *46.0*	18.5 *47.0*	18.5 *47.0*	18.8 *47.8*	Head circ.	34	16.9 *43.0*	16.9 *43.0*	17.3 *44.0*	17.7 *45.0*	18.0 *45.7*	18.1 *46.0*	18.3 *46.5*
								11 months								
28	18.7 *8.50*	19.5 *8.86*	20.7 *9.37*	22.0 *10.00*	23.1 *10.46*	23.5 *10.64*	23.9 *10.86*	Weight	34	17.1 *7.77*	17.6 *8.00*	18.6 *8.43*	20.2 *9.14*	22.0 *9.99*	23.3 *10.59*	24.0 *10.90*
28	28.1 *71.3*	28.9 *73.3*	29.1 *74.0*	29.7 *75.5*	29.9 *76.0*	30.4 *77.1*	30.6 *77.8*	Length	34	27.8 *70.5*	27.9 *70.8*	28.1 *71.5*	28.9 *73.5*	29.4 *74.7*	29.7 *75.5*	30.2 *76.6*
28	17.9 *45.4*	18.1 *46.0*	18.3 *46.5*	18.7 *47.5*	18.9 *48.0*	19.3 *49.0*	19.5 *49.6*	Sitting height	33	17.4 *44.3*	17.6 *44.6*	18.0 *45.6*	18.4 *46.7*	18.7 *47.5*	19.0 *48.3*	19.2 *48.8*
27	17.5 *44.5*	17.7 *45.0*	17.9 *45.5*	18.5 *47.0*	18.7 *47.5*	18.9 *48.0*	18.9 *48.0*	Head circ.	33	17.2 *43.8*	17.3 *44.0*	17.5 *44.5*	17.9 *45.5*	18.1 *46.0*	18.5 *46.9*	18.5 *47.1*
								12 months								
58	18.7 *8.50*	20.2 *9.17*	21.1 *9.57*	22.2 *10.09*	23.8 *10.78*	24.5 *11.13*	25.0 *11.36*	Weight	73	18.1 *8.22*	18.5 *8.40*	19.5 *8.86*	21.0 *9.51*	22.1 *10.04*	24.4 *11.05*	25.0 *11.33*
58	28.1 *71.4*	28.9 *73.4*	29.5 *75.0*	30.1 *76.5*	30.5 *77.5*	31.1 *79.0*	31.3 *79.5*	Length	72	28.0 *71.0*	28.3 *72.0*	28.7 *73.0*	29.4 *74.7*	29.9 *76.0*	30.3 *77.0*	30.5 *77.5*
56	18.0 *45.8*	18.3 *46.5*	18.7 *47.5*	18.9 *48.0*	19.3 *49.0*	20.0 *50.7*	20.1 *51.1*	Sitting height	71	17.5 *44.5*	17.7 *45.0*	18.2 *46.3*	18.7 *47.5*	18.9 *48.0*	19.3 *48.9*	19.5 *49.5*
58	17.5 *44.5*	17.7 *45.0*	18.1 *46.0*	18.5 *47.0*	18.9 *48.0*	19.1 *48.5*	19.1 *48.5*	Head circ.	72	17.2 *43.8*	17.5 *44.5*	17.7 *45.0*	18.1 *46.0*	18.3 *46.5*	18.5 *47.0*	18.7 *47.5*
26	17.5 *44.5*	17.6 *44.8*	18.1 *46.0*	18.5 *47.0*	18.9 *48.0*	19.3 *49.0*	19.6 *49.7*	Chest circ.	31	16.7 *42.5*	17.3 *44.0*	17.8 *45.3*	18.1 *46.0*	18.5 *47.1*	18.7 *47.5*	19.0 *48.2*

[1] HEIMENDINGER, J., *Helv. pædiat. Acta*, 19, 406 (1964). From measurements made in the period 1957–1962 in northwest Switzerland on 341 boys and 326 girls mostly of German-Swiss descent.

Normal Measurements During Growth – 15 Months to 2 Years

Weight in pounds and *kilogrammes*, other measurements in inches and *centimetres* (P = percentile)

Boys P_{3}	Boys P_{10}	Boys P_{25}	Boys P_{50}	Boys P_{75}	Boys P_{90}	Boys P_{97}		Girls Number	Girls P_{3}	Girls P_{10}	Girls P_{25}	Girls P_{50}	Girls P_{75}	Girls P_{90}	Girls P_{97}
							15 months[1]								
20.8 *9.45*	21.6	22.5	24.0	25.3	26.9	28.5	Weight	46	19.7 *8.92*	20.0 *9.06*	21.4 *9.69*	22.4 *10.15*	24.1 *10.92*	24.9 *11.29*	25.6 *11.61*
29.6 *75.2*							Length	46	29.5 *75.0*	29.7 *75.5*	30.1 *76.5*	30.7 *78.0*	31.3 *79.5*	31.7 *80.5*	31.9 *81.0*
18.8 *47.8*							Sitting height	46	18.3 *46.5*	18.3 *46.5*	18.9 *48.0*	19.1 *48.5*	19.5 *49.5*	20.0 *50.7*	20.2 *51.3*
17.9 *45.5*							Head circ	45	17.5 *44.5*	17.7 *45.0*	18.1 *46.0*	18.5 *47.0*	18.7 *47.5*	18.9 *48.0*	19.1 *48.5*
17.9 *45.5*							Chest circ	28	17.1 *43.4*	17.6 *44.8*	18.1 *46.0*	18.5 *47.0*	18.7 *47.5*	18.9 *48.1*	19.4 *49.4*
							18 months[1]								
22.3	22.8	24.1	24.9	26.5	28.5	29.3	Weight	40	21.1	22.4	23.1	24.1	26.2	27.4	28.7
							Length	40	3 *7*						
							Sitting height	40	1 *4*						
							Head circ	40	1 *4*						
							Chest circ.	22	1 *4*						
							2 years[1]								
3	24.1 *10.91*	25.0	26.1	27.6	29.5	30.7	Weight	24	22.1	23.3	24.7	26.7	28.6	30.2	31.0
4	33.1 *84.0*						Height	24							
4	20.1 *51.1*						Sitting height	24							
4	18.5 *47.1*						Head circ	24							
0	18.7 *47.5*						Chest circ	10							

(Boys: 90% spans P_{3}–P_{97}; 80% spans P_{10}–P_{90}; 50% spans P_{25}–P_{75}. Girls likewise.)

Boys $P_{2.5}$	Boys P_{10}	Boys P_{25}	Boys P_{50}	Boys P_{75}	Boys P_{90}	Boys $P_{97.5}$	Boys s		Girls $P_{2.5}$	Girls P_{10}	Girls P_{25}	Girls P_{50}	Girls P_{75}	Girls P_{90}	Girls $P_{97.5}$	Girls s
								2 years[2]								
18.3 *8.3*	21.4 *9.7*	24.3 *11.0*	27.3 *12.4*	30.4 *13.8*	33.3 *15.1*	36.4 *16.5*	4.5 *2.05*	Weight	20.1 *9.1*	22.3 *10.1*	24.0 *10.9*	26.2 *11.9*	28.4 *12.9*	30.2 *13.7*	32.4 *14.7*	3.1 *1.4*
31.1 *78.9*	32.2 *81.7*	33.1 *84.2*	34.3 *87.0*	35.4 *89.8*	36.3 *92.3*	37.4 *95.1*	1.6 *4.1*	Height	31.0 *78.8*	32.0 *81.4*	33.0 *83.8*	34.1 *86.5*	35.1 *89.2*	36.1 *91.6*	37.1 *94.2*	1.5 *3.9*
18.9 *48.1*	19.6 *49.8*	20.2 *51.3*	20.8 *52.9*	21.5 *54.5*	22.0 *56.0*	22.7 *57.7*	0.9 *2.4*	Sitting height	18.3 *46.4*	19.1 *48.6*	19.9 *50.5*	20.7 *52.7*	21.6 *54.9*	22.4 *56.8*	23.2 *59.0*	1.3 *3.2*
4.9 *12.4*	5.8 *14.8*	6.7 *16.9*	7.6 *19.3*	8.5 *21.7*	9.4 *23.8*	10.3 *26.2*	1.4 *3.5*	Shoulder width	5.9 *15.0*	6.6 *16.8*	7.2 *18.3*	7.9 *20.0*	8.5 *21.7*	9.1 *23.2*	9.8 *25.0*	1.0 *2.5*
4.6 *11.7*	5.4 *13.7*	6.1 *15.6*	6.9 *17.6*	7.7 *19.6*	8.5 *21.5*	9.3 *23.5*	1.2 *3.0*	Pelvic width	4.9 *12.4*	5.5 *14.0*	6.0 *15.3*	6.6 *16.8*	7.2 *18.3*	7.7 *19.6*	8.4 *21.2*	0.9 *2.2*
18.3 *46.4*	18.7 *47.4*	19.0 *48.2*	19.4 *49.2*	19.8 *50.2*	20.1 *51.0*	20.5 *52.0*	0.6 *1.4*	Head circ	17.6 *44.6*	18.0 *45.6*	18.3 *46.4*	18.7 *47.4*	19.1 *48.4*	19.4 *49.2*	19.8 *50.2*	0.6 *1.4*
17.8 *45.2*	18.4 *46.8*	18.9 *48.1*	19.5 *49.6*	20.1 *51.1*	20.6 *52.4*	21.3 *54.0*	0.9 *2.2*	Chest circ	17.1 *43.5*	17.8 *45.2*	18.4 *46.7*	19.0 *48.3*	19.6 *49.9*	20.2 *51.4*	20.9 *53.1*	0.9 *2.4*
5.3 *13.5*	5.6 *14.2*	5.8 *14.8*	6.1 *15.5*	6.4 *16.2*	6.6 *16.8*	6.9 *17.5*	0.4 *1.0*	Upper arm circ	4.1 *10.5*	4.7 *12.0*	5.2 *13.3*	5.8 *14.7*	6.3 *16.1*	6.9 *17.4*	7.4 *18.9*	0.8 *2.1*
1.6 *4.1*	2.4 *6.1*	3.1 *8.0*	3.9 *10.0*	4.7 *12.0*	5.5 *13.9*	6.3 *15.9*	1.2 *3.0*	Wrist circ	1.6 *4.1*	2.4 *6.0*	3.0 *7.7*	3.8 *9.6*	4.5 *11.5*	5.2 *13.2*	5.9 *15.1*	1.1 *2.8*
6.7 *17.0*	7.0 *17.7*	7.2 *18.3*	7.5 *19.0*	7.8 *19.7*	8.0 *20.3*	8.3 *21.0*	0.4 *1.0*	Calf circ	5.6 *14.1*	6.2 *15.7*	6.7 *17.0*	7.3 *18.5*	7.9 *20.0*	8.4 *21.3*	9.0 *22.9*	0.9 *2.2*

(95% spans $P_{2.5}$–$P_{97.5}$; 80% spans P_{10}–P_{90}; 50% spans P_{25}–P_{75}.)

[1] HEIMENDINGER, J., *Helv paediat Acta*, 19, 406 (1964). From measurements made in the period 1957–1962 in northwest Switzerland on 341 boys and 326 girls mostly of German Swiss descent

[2] HEIMENDINGER, J., *Helv paediat Acta*, 19, suppl 13 (1964). From measurements made in the period 1956–1957 on 2150 boys and 2150 girls in Basle, Switzerland

Normal Measurements During Growth – 2½ Years to 3½ Years[1]

Weight in pounds and *kilogrammes*; other measurements in inches and *centimetres* (P = percentile)

Boys									Girls							
	95%									95%						
		80%									80%					
			50%									50%				
$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s		$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s
								2½ years								
20.5	23.8	26.7	29.8	32.8	35.7	39.0	4.7	Weight	21.4	24.0	26.2	28.9	31.5	33.7	36.4	3.7
9.3	*10.8*	*12.1*	*13.5*	*14.9*	*16.2*	*17.7*	*2.11*		*9.7*	*10.9*	*11.9*	*13.1*	*14.3*	*15.3*	*16.5*	*1.7*
33.1	34.3	35.2	36.4	37.5	38.5	39.6	1.7	Height	32.6	33.7	34.7	35.8	36.9	37.9	39.0	1.6
84.1	*87.0*	*89.5*	*92.4*	*95.3*	*97.8*	*100.7*	*4.2*		*82.9*	*85.7*	*88.2*	*91.0*	*93.8*	*96.3*	*99.1*	*4.1*
19.6	20.3	20.9	21.6	22.3	23.0	23.6	1.0	*Sitting height*	18.8	19.6	20.4	21.2	22.0	22.8	23.6	1.2
49.8	*51.5*	*53.1*	*54.9*	*56.7*	*58.3*	*60.0*	*2.6*		*47.7*	*49.8*	*51.7*	*53.8*	*55.9*	*57.8*	*59.9*	*3.1*
5.2	6.1	7.0	8.0	8.9	9.8	10.7	1.4	Shoulder width	6.2	6.9	7.5	8.1	8.8	9.4	10.1	1.0
13.1	*15.5*	*17.7*	*20.2*	*22.7*	*24.9*	*27.3*	*3.6*		*15.7*	*17.5*	*19.0*	*20.7*	*22.4*	*23.9*	*25.7*	*2.5*
4.5	5.4	6.1	7.0	7.9	8.6	9.5	1.3	Pelvic width	5.0	5.6	6.2	6.8	7.4	8.0	8.6	0.9
11.5	*13.7*	*15.6*	*17.8*	*20.0*	*21.9*	*24.1*	*3.2*		*12.7*	*14.3*	*15.7*	*17.3*	*18.9*	*20.3*	*21.9*	*2.3*
18.4	18.8	19.1	19.5	19.9	20.2	20.6	0.6	Head circ.	17.8	18.2	18.5	18.9	19.3	19.6	20.0	0.6
46.8	*47.8*	*48.6*	*49.6*	*50.6*	*51.4*	*52.4*	*1.4*		*45.3*	*46.3*	*47.1*	*48.1*	*49.1*	*49.9*	*50.9*	*1.4*
17.9	18.5	19.1	19.8	20.4	21.0	21.7	0.9	Chest circ.	17.5	18.2	18.8	19.4	20.0	20.6	21.3	0.9
45.4	*47.1*	*48.6*	*50.2*	*51.8*	*53.3*	*55.0*	*2.4*		*44.5*	*46.2*	*47.7*	*49.3*	*50.9*	*52.4*	*54.1*	*2.4*
5.2	5.5	5.8	6.1	6.5	6.8	7.1	0.5	Upper arm circ.	4.3	4.9	5.4	5.9	6.5	6.9	7.5	0.8
13.2	*14.0*	*14.8*	*15.6*	*16.4*	*17.2*	*18.0*	*1.2*		*11.0*	*12.4*	*13.6*	*15.0*	*16.4*	*17.6*	*19.0*	*2.0*
1.7	2.5	3.2	4.0	4.8	5.6	6.3	1.2	Wrist circ.	1.5	2.3	3.0	3.8	4.6	5.3	6.0	1.1
4.3	*6.3*	*8.2*	*10.2*	*12.2*	*14.1*	*16.1*	*3.0*		*3.9*	*5.8*	*7.6*	*9.6*	*11.6*	*13.4*	*15.3*	*2.9*
6.1	6.7	7.1	7.7	8.2	8.7	9.3	0.8	Calf circ.	5.8	6.4	6.9	7.5	8.1	8.6	9.3	0.9
15.5	*16.9*	*18.1*	*19.5*	*20.9*	*22.1*	*23.5*	*2.0*		*14.7*	*16.3*	*17.6*	*19.1*	*20.6*	*21.9*	*23.5*	*2.2*
								3 years								
23.1	26.2	29.1	32.2	35.3	38.1	41.2	4.5	Weight	22.7	25.8	28.4	31.5	34.6	37.3	40.3	4.4
10.5	*11.9*	*13.2*	*14.6*	*16.0*	*17.3*	*18.7*	*2.06*		*10.3*	*11.7*	*12.9*	*14.3*	*15.7*	*16.9*	*18.3*	*2.0*
34.7	35.8	36.8	37.9	39.0	40.0	41.1	1.6	Height	34.1	35.3	36.3	37.5	38.6	39.7	40.8	1.7
88.2	*91.0*	*93.5*	*96.3*	*99.1*	*101.6*	*104.4*	*4.1*		*86.7*	*89.6*	*92.3*	*95.2*	*98.1*	*100.8*	*103.7*	*4.3*
19.7	20.5	21.3	22.1	22.9	23.7	24.5	1.2	Sitting height	19.4	20.1	20.8	21.6	22.4	23.1	23.9	1.1
50.0	*52.1*	*54.0*	*56.1*	*58.2*	*60.1*	*62.2*	*3.1*		*49.2*	*51.1*	*52.9*	*54.9*	*56.9*	*58.7*	*60.6*	*2.9*
5.4	6.4	7.3	8.3	9.3	10.2	11.2	1.5	Shoulder width	6.4	7.0	7.7	8.4	9.1	9.7	10.4	1.0
13.8	*16.3*	*18.6*	*21.1*	*23.6*	*25.9*	*28.4*	*3.7*		*16.2*	*17.9*	*19.5*	*21.3*	*23.1*	*24.7*	*26.4*	*2.6*
4.4	5.4	6.2	7.1	8.1	8.9	9.8	1.4	Pelvic width	5.2	5.8	6.3	7.0	7.6	8.1	8.8	0.9
11.2	*13.6*	*15.7*	*18.1*	*20.5*	*22.6*	*25.0*	*3.5*		*13.1*	*14.7*	*16.1*	*17.7*	*19.3*	*20.7*	*22.3*	*2.3*
18.5	18.9	19.3	19.6	20.0	20.4	20.7	0.6	Head circ.	18.0	18.4	18.7	19.1	19.5	19.9	20.3	0.6
47.1	*48.1*	*48.9*	*49.9*	*50.9*	*51.7*	*52.7*	*1.4*		*45.6*	*46.7*	*47.6*	*48.6*	*49.6*	*50.5*	*51.6*	*1.5*
17.3	18.2	19.1	20.0	20.9	21.8	22.7	1.4	Chest circ.	17.9	18.6	19.2	19.8	20.5	21.1	21.8	1.0
43.9	*46.3*	*48.4*	*50.8*	*53.2*	*55.3*	*57.7*	*3.5*		*45.4*	*47.2*	*48.7*	*50.4*	*52.1*	*53.6*	*55.4*	*2.5*
5.1	5.5	5.8	6.2	6.6	6.9	7.3	0.6	Upper arm circ.	4.5	5.0	5.5	6.0	6.5	7.0	7.5	0.7
12.9	*13.9*	*14.7*	*15.7*	*16.7*	*17.5*	*18.5*	*1.4*		*11.5*	*12.8*	*14.0*	*15.3*	*16.6*	*17.8*	*19.1*	*1.9*
1.7	2.5	3.3	4.1	4.9	5.7	6.5	1.2	Wrist circ.	1.5	2.3	3.1	3.9	4.6	5.4	6.2	1.2
4.3	*6.4*	*8.3*	*10.4*	*12.5*	*14.4*	*16.5*	*3.1*		*3.9*	*5.9*	*7.8*	*9.8*	*11.8*	*13.7*	*15.7*	*3.0*
6.2	6.8	7.3	7.8	8.4	8.9	9.5	0.8	Calf circ.	6.2	6.7	7.2	7.7	8.2	8.7	9.2	0.7
15.7	*17.2*	*18.5*	*19.9*	*21.3*	*22.6*	*24.1*	*2.1*		*15.8*	*17.1*	*18.3*	*19.6*	*20.9*	*22.1*	*23.4*	*1.9*
								3½ years								
25.8	28.9	31.5	34.6	37.7	40.3	43.4	4.5	Weight	24.0	27.6	30.4	33.7	37.0	39.9	43.4	4.9
11.7	*13.1*	*14.3*	*15.7*	*17.1*	*18.3*	*19.7*	*2.03*		*10.9*	*12.5*	*13.8*	*15.3*	*16.8*	*18.1*	*19.7*	*2.2*
36.1	37.2	38.2	39.4	40.5	41.5	42.6	1.7	Height	35.5	36.7	37.7	38.9	40.1	41.1	42.3	1.7
91.7	*94.6*	*97.1*	*100.0*	*102.9*	*105.4*	*108.3*	*4.2*		*90.1*	*93.1*	*95.8*	*98.8*	*101.8*	*104.5*	*107.5*	*4.4*
19.5	20.5	21.5	22.5	23.6	24.5	25.6	1.5	Sitting height	19.9	20.6	21.3	22.0	22.8	23.5	24.2	1.1
49.5	*52.1*	*54.5*	*57.2*	*59.9*	*62.3*	*64.9*	*3.9*		*50.5*	*52.4*	*54.1*	*56.0*	*57.9*	*59.6*	*61.5*	*2.8*
5.8	6.8	7.6	8.6	9.6	10.5	11.4	1.4	Shoulder width	6.7	7.3	8.0	8.7	9.4	10.0	10.7	1.0
14.8	*17.2*	*19.4*	*21.9*	*24.4*	*26.6*	*29.0*	*3.6*		*16.9*	*18.6*	*20.2*	*22.0*	*23.8*	*25.4*	*27.1*	*2.6*
4.2	5.2	6.2	7.2	8.3	9.3	10.3	1.5	Pelvic width	5.4	6.0	6.5	7.1	7.7	8.2	8.9	0.9
10.7	*13.3*	*15.7*	*18.4*	*21.1*	*23.5*	*26.1*	*3.9*		*13.7*	*15.3*	*16.6*	*18.1*	*19.6*	*20.9*	*22.5*	*2.2*
18.7	19.1	19.4	19.8	20.2	20.5	20.9	0.6	Head circ.	18.3	18.7	19.0	19.3	19.7	20.0	20.4	0.5
47.5	*48.5*	*49.3*	*50.3*	*51.3*	*52.1*	*53.1*	*1.4*		*46.5*	*47.4*	*48.2*	*49.1*	*50.0*	*50.8*	*51.7*	*1.3*
15.2	17.0	18.5	20.2	22.0	23.5	25.2	2.5	Chest circ.	18.2	18.9	19.5	20.2	20.9	21.5	22.2	1.0
38.7	*43.1*	*47.0*	*51.4*	*55.8*	*59.7*	*64.1*	*6.4*		*46.3*	*48.1*	*49.6*	*51.3*	*53.0*	*54.5*	*56.3*	*2.5*
4.8	5.3	5.7	6.2	6.7	7.1	7.6	0.7	Upper arm circ.	4.8	5.3	5.7	6.1	6.6	7.0	7.5	0.7
12.2	*13.5*	*14.6*	*15.8*	*17.0*	*18.1*	*19.4*	*1.8*		*12.2*	*13.4*	*14.4*	*15.6*	*16.8*	*17.8*	*19.0*	*1.7*
1.8	2.6	3.3	4.2	5.0	5.7	6.6	1.2	Wrist circ.	1.6	2.4	3.1	3.9	4.7	5.5	6.3	1.2
4.5	*6.6*	*8.5*	*10.6*	*12.7*	*14.6*	*16.7*	*3.1*		*4.1*	*6.1*	*8.0*	*10.0*	*12.0*	*13.9*	*15.9*	*3.0*
6.3	6.9	7.4	8.0	8.6	9.1	9.8	0.9	Calf circ.	6.7	7.2	7.5	7.9	8.3	8.7	9.1	0.6
16.0	*17.6*	*18.9*	*20.4*	*21.9*	*23.2*	*24.8*	*2.2*		*17.1*	*18.2*	*19.1*	*20.1*	*21.1*	*22.0*	*23.1*	*1.5*

[1] HEIMENDINGER, J., *Helv. paediat. Acta*, 19, suppl. 13 (1964). From measurements made in the period 1956–1957 on 2150 boys and 2150 girls in Basle, Switzerland.

Normal Measurements During Growth – 4 Years to 5 Years[1]

Weight in pounds and *kilogrammes*, other measurements in inches and *centimetres* (P = percentile)

Boys P_3	Boys P_{10}	Boys P_{25}	Boys P_{50}	Boys P_{75}	Boys P_{90}	Boys P_{97}	Boys s		Girls P_3	Girls P_{10}	Girls P_{25}	Girls P_{50}	Girls P_{75}	Girls P_{90}	Girls P_{97}	Girls s
		95%									95%					
		80%									80%					
			50%									50%				
								4 years								
.8	30.9	33.7	36.8	39.9	42.8	45.9	4.5	Weight	25.8	29.3	32.4	35.9	39.5	42.5	46.1	5.1
6	*14.0*	*15.3*	*16.7*	*18.1*	*19.4*	*20.8*	*2.05*		*11.7*	*13.3*	*14.7*	*16.3*	*17.9*	*19.3*	*20.9*	*2.3*
4	38.5	39.6	40.7	41.9	43.0	44.1	1.7	Height	36.8	38.0	39.1	40.3	41.5	42.6	43.8	1.8
.0							*4.3*		*93.4*	*96.5*	*99.2*	*102.3*	*105.4*	*108.1*	*111.2*	*4.5*
8							1.6	Sitting height	20.4	21.1	21.8	22.5	23.2	23.9	24.6	1.1
3							*4.0*		*51.8*	*53.6*	*55.3*	*57.1*	*58.9*	*60.6*	*62.4*	*2.7*
5.5							1.1	Shoulder width	6.9	7.6	8.2	8.9	9.6	10.3	10.9	1.0
5.4							*2.8*		*17.6*	*19.3*	*20.9*	*22.7*	*24.5*	*26.1*	*27.8*	*2.6*
4.8							1.3	Pelvic width	5.6	6.2	6.7	7.3	7.8	8.3	8.7	0.8
2.3							*3.3*		*14.3*	*15.8*	*17.1*	*18.5*	*19.9*	*21.2*	*22.2*	*2.1*
8.8							0.6	Head circ	18.5	18.9	19.2	19.5	19.9	20.2	20.6	0.5
7.8							*1.4*		*47.0*	*47.9*	*48.7*	*49.6*	*50.5*	*51.3*	*52.2*	*1.3*
5.2							2.7	Chest circ.	18.4	19.1	19.7	20.4	21.0	21.6	22.3	1.0
6							*6.8*		*46.7*	*48.5*	*50.0*	*51.7*	*53.4*	*54.9*	*56.7*	*2.5*
4.5							0.9	Upper arm circ.	5.2	5.6	5.9	6.3	6.7	7.0	7.4	0.6
1.5							*2.2*		*13.1*	*14.1*	*14.9*	*15.9*	*16.9*	*17.7*	*18.7*	*1.4*
1.9							1.2	Wrist circ	1.8	2.6	3.3	4.1	4.8	5.6	6.3	1.1
4.9							*3.0*		*4.6*	*6.5*	*8.3*	*10.3*	*12.3*	*14.1*	*16.0*	*2.9*
6.4							0.9	Calf circ.	7.0	7.4	7.8	8.1	8.5	8.9	9.3	0.6
6.3							*2.3*		*17.9*	*18.9*	*19.7*	*20.7*	*21.7*	*22.5*	*23.5*	*1.4*
								4½ years								
30.0	33.3	36.2	39.2	42.3	45.2	48.5	4.7	Weight	27.6	31.3	34.6	38.1	41.7	45.0	48.7	5.3
13.6	*15.1*	*16.4*	*17.8*	*19.2*	*20.5*	*22.0*	*2.12*		*12.5*	*14.2*	*15.7*	*17.3*	*18.9*	*20.4*	*22.1*	*2.4*
38.6	39.8	40.9	42.1	43.3	44.4	45.6	1.8	Height	38.1	39.4	40.4	41.7	42.9	43.9	45.2	1.8
98.0	*101.1*	*103.8*	*106.9*	*110.0*	*112.7*	*115.8*	*4.5*		*96.9*	*100.0*	*102.7*	*105.8*	*108.9*	*111.6*	*114.7*	*4.5*
20.7	21.6	22.4	23.3	24.2	25.0	25.9	1.3	Sitting height	20.7	21.4	22.1	22.9	23.7	24.4	25.2	1.1
52.7	*54.9*	*57.0*	*59.2*	*61.4*	*63.5*	*65.7*	*3.3*		*52.5*	*54.4*	*56.2*	*58.2*	*60.2*	*62.0*	*63.9*	*2.9*
7.0	8.0	8.6	9.3	9.9	10.5	10.9	1.0	Shoulder width	7.3	8.0	8.5	9.2	9.8	10.4	11.1	0.9
17.7	*20.3*	*21.8*	*23.5*	*25.2*	*26.7*	*27.7*	*2.5*		*18.5*	*20.2*	*21.7*	*23.3*	*24.9*	*26.4*	*28.1*	*2.4*
5.6	6.3	6.9	7.5	8.2	8.8	9.5	1.0	Pelvic width	6.0	6.5	7.0	7.4	7.9	8.3	8.9	0.7
14.1	*15.9*	*17.4*	*19.1*	*20.8*	*22.3*	*24.1*	*2.5*		*15.3*	*16.6*	*17.7*	*18.9*	*20.1*	*21.2*	*22.5*	*1.8*
18.9	19.3	19.6	20.0	20.4	20.7	21.1	0.6	Head circ	18.6	19.0	19.3	19.7	20.1	20.4	20.8	0.6
48.0	*49.0*	*49.8*	*50.8*	*51.8*	*52.6*	*53.6*	*1.4*		*47.2*	*48.2*	*49.0*	*50.0*	*51.0*	*51.8*	*52.8*	*1.4*
15.4	17.3	18.9	20.7	22.6	24.2	26.1	2.7	Chest circ	18.5	19.2	19.8	20.5	21.2	21.9	22.5	1.0
39.2	*43.9*	*48.1*	*52.7*	*57.3*	*61.5*	*66.2*	*6.8*		*47.0*	*48.7*	*50.3*	*52.1*	*53.9*	*55.5*	*57.2*	*2.6*
4.6	5.2	5.7	6.3	6.9	7.4	8.1	0.9	Upper arm circ	5.4	5.7	6.1	6.4	6.7	7.0	7.3	0.5
11.7	*13.3*	*14.6*	*16.1*	*17.6*	*18.9*	*20.5*	*2.2*		*13.8*	*14.6*	*15.4*	*16.2*	*17.0*	*17.8*	*18.6*	*1.2*
2.0	2.8	3.6	4.4	5.2	5.9	6.7	1.2	Wrist circ	2.2	2.9	3.5	4.3	5.0	5.6	6.3	1.1
5.2	*7.2*	*9.1*	*11.1*	*13.1*	*15.0*	*17.0*	*3.0*		*5.5*	*7.3*	*9.0*	*10.8*	*12.6*	*14.3*	*16.1*	*2.7*
6.5	7.2	7.8	8.4	9.1	9.6	10.2	0.9	Calf circ	7.2	7.6	8.0	8.3	8.7	9.1	9.4	0.6
16.6	*18.3*	*19.8*	*21.4*	*23.0*	*24.5*	*26.0*	*2.4*		*18.4*	*19.4*	*20.2*	*21.2*	*22.2*	*23.0*	*24.0*	*1.4*
								5 years								
32.2	35.5	38.4	41.7	45.0	47.8	51.1	4.8	Weight	29.8	33.5	36.8	40.3	43.9	47.2	50.9	5.3
14.6	*16.1*	*17.4*	*18.9*	*20.4*	*21.7*	*23.2*	*2.19*		*13.5*	*15.2*	*16.7*	*18.3*	*19.9*	*21.4*	*23.1*	*2.4*
39.8	41.0	42.2	43.4	44.6	45.7	47.0	1.8	Height	39.6	40.7	41.8	43.0	44.2	45.2	46.4	1.7
101.1	*104.2*	*107.1*	*110.2*	*113.3*	*116.2*	*119.3*	*4.6*									*4.4*
21.5	22.2	22.9	23.7	24.5	25.2	25.9	1.1	Sitting height								1.2
54.5	*56.4*	*58.2*	*60.2*	*62.2*	*64.0*	*65.9*	*2.9*									*3.1*
7.4	8.3	8.9	9.5	10.2	10.7	11.1	0.9	Shoulder width								0.8
18.9	*21.2*	*22.6*	*24.2*	*25.8*	*27.2*	*28.1*	*2.3*									*2.1*
5.9	6.6	7.1	7.7	8.3	8.8	9.4	0.9	Pelvic width								0.6
15.1	*16.7*	*18.0*	*19.5*	*21.0*	*22.3*	*23.9*	*2.2*									*1.6*
18.9	19.3	19.7	20.1	20.5	20.8	21.3	0.6	Head circ								0.6
48.0	*49.1*	*50.0*	*51.0*	*52.0*	*52.9*	*54.0*	*1.5*									*1.4*
15.9	17.7	19.3	21.0	22.8	24.3	26.1	2.6	Chest circ								1.0
40.5	*45.0*	*49.0*	*53.4*	*57.8*	*61.8*	*66.3*	*6.5*		*47.4*	*49.1*	*50.7*	*52.5*	*54.3*	*55.9*	*57.6*	*2.6*
5.0	5.5	5.9	6.4	6.9	7.3	7.8	0.7	Upper arm circ	5.7	6.0	6.3	6.5	6.8	7.1	7.4	0.4
12.7	*14.0*	*15.1*	*16.3*	*17.5*	*18.6*	*19.9*	*1.8*		*14.4*	*15.2*	*15.9*	*16.6*	*17.3*	*18.0*	*18.8*	*1.1*
2.2	3.0	3.7	4.4	5.2	5.9	6.7	1.1	Wrist circ	2.6	3.3	3.8	4.4	5.0	5.5	6.1	0.9
5.6	*7.5*	*9.3*	*11.3*	*13.3*	*15.1*	*17.0*	*2.9*		*6.7*	*8.3*	*9.6*	*11.1*	*12.6*	*13.9*	*15.5*	*2.2*
6.7	7.4	8.0	8.6	9.2	9.8	10.5	0.9	Calf circ	7.5	7.9	8.2	8.6	9.0	9.3	9.7	0.6
17.0	*18.7*	*20.2*	*21.8*	*23.4*	*24.9*	*26.6*	*2.4*		*19.0*	*20.0*	*20.8*	*21.8*	*22.8*	*23.6*	*24.6*	*1.4*

[1] HEIMENDINGER, J., *Helv paediat Acta* 19, suppl 13 (1964) From measurements made in the period 1956–1957 on 2150 boys and 2150 girls in Basle, Switzerland

Normal Measurements During Growth – 5½ Years to 6½ Years[1]

Weight in pounds and *kilogrammes*; other measurements in inches and *centimetres* (P = percentile)

Boys									Girls							
95%									95%							
	80%									80%						
		50%									50%					
$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s		$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s
								5½ years								
34.2	37.7	40.8	44.1	47.4	50.5	54.0	5.0	Weight	31.7	35.7	39.0	42.8	46.5	49.8	53.8	[illegible]
15.5	17.1	18.5	20.0	21.5	22.9	24.5	2.25		14.4	16.2	17.7	19.4	21.1	22.6	24.4	[illegible]
40.9	42.2	43.3	44.6	45.9	47.1	48.4	1.9	Height	40.8	42.0	43.1	44.3	45.6	46.6	47.8	1.8
103.9	107.2	110.1	113.4	116.7	119.6	122.9	4.8		103.7	106.8	109.5	112.6	115.7	118.4	121.5	[illegible]
21.8	22.6	23.3	24.1	24.9	25.6	26.4	1.2	Sitting height	21.3	22.2	22.9	23.8	24.6	25.4	26.3	1.3
55.3	57.3	59.2	61.2	63.2	65.1	67.1	3.0		54.1	56.3	58.2	60.4	62.6	64.5	66.7	3.2
7.8	8.7	9.2	9.8	10.4	10.9	11.3	0.9	Shoulder width	8.1	8.7	9.2	9.7	10.3	10.7	11.3	0.8
19.8	22.1	23.4	24.9	26.4	27.7	28.6	2.2		20.7	22.1	23.3	24.7	26.1	27.3	28.7	2.0
6.1	6.7	7.2	7.8	8.3	8.9	9.4	0.8	Pelvic width	6.5	6.9	7.3	7.8	8.3	8.7	9.1	0.7
15.6	17.1	18.4	19.8	21.2	22.5	24.0	2.1		16.4	17.6	18.6	19.8	21.0	22.0	23.2	1.7
18.9	19.3	19.7	20.2	20.6	21.0	21.4	0.6	Head circ.	18.7	19.1	19.5	19.9	20.4	20.7	21.2	0.6
48.0	49.1	50.1	51.2	52.3	53.3	54.4	1.6		47.4	48.5	49.5	50.6	51.7	52.7	53.8	1.6
18.0	19.1	20.2	21.3	22.5	23.5	24.7	1.7	Chest circ.	18.7	19.4	20.1	20.8	21.5	22.2	22.9	1.1
45.7	48.6	51.3	54.2	57.1	59.8	62.7	4.3		47.6	49.4	51.1	52.9	54.7	56.4	58.2	2.7
5.6	5.9	6.2	6.5	6.9	7.2	7.5	0.5	Upper arm circ.	5.8	6.1	6.4	6.7	6.9	7.2	7.5	0.4
14.2	15.0	15.8	16.6	17.4	18.2	19.0	1.2		14.7	15.5	16.2	16.9	17.6	18.3	19.1	1.1
2.6	3.3	3.9	4.5	5.2	5.8	6.5	1.0	Wrist circ.	3.2	3.6	4.0	4.4	4.9	5.3	5.7	0.6
6.5	8.3	9.8	11.5	13.2	14.7	16.5	2.5		8.1	9.2	10.2	11.3	12.4	13.4	14.5	1.6
6.9	7.6	8.1	8.8	9.4	10.0	10.7	0.9	Calf circ.	7.6	8.0	8.4	8.8	9.2	9.5	10.0	0.6
17.5	19.2	20.7	22.3	23.9	25.4	27.1	2.4		19.3	20.4	21.3	22.3	23.3	24.2	25.3	1.5
								6 years								
36.2	39.7	42.8	46.3	49.8	52.9	56.4	5.1	Weight	32.8	37.0	41.0	45.4	49.8	53.8	58.0	6.4
16.4	18.0	19.4	21.0	22.6	24.0	25.6	2.32		14.9	16.8	18.6	20.6	22.6	24.4	26.3	2.9
42.0	43.4	44.6	45.9	47.2	48.3	49.7	1.9	Height	41.7	43.1	44.3	45.6	47.0	48.2	49.5	2.0
106.8	110.2	113.2	116.5	119.8	122.8	126.2	4.9		106.0	109.4	112.5	115.9	119.3	122.4	125.8	5.0
22.0	22.9	23.6	24.5	25.4	26.1	27.0	1.3	Sitting height	21.8	22.6	23.4	24.2	25.0	25.8	26.6	1.2
55.9	58.1	60.0	62.2	64.4	66.3	68.5	3.2		55.4	57.5	59.4	61.5	63.6	65.5	67.6	3.1
8.2	9.0	9.5	10.0	10.6	11.1	11.4	0.8	Shoulder width	8.4	8.9	9.4	10.0	10.5	11.0	11.5	0.8
20.9	22.9	24.1	25.5	26.9	28.1	28.9	2.0		21.3	22.7	23.9	25.3	26.7	27.9	29.3	2.0
6.4	6.9	7.4	8.0	8.5	9.0	9.5	0.8	Pelvic width	6.5	7.0	7.5	8.0	8.4	8.9	9.4	0.7
16.2	17.6	18.8	20.2	21.6	22.8	24.2	2.0		16.6	17.9	19.0	20.2	21.4	22.5	23.8	1.8
18.4	19.1	19.6	20.2	20.9	21.4	22.0	0.9	Head circ.	18.6	19.1	19.5	20.0	20.5	20.9	21.4	0.7
46.8	48.4	49.8	51.4	53.0	54.4	56.0	2.3		47.2	48.5	49.6	50.8	52.0	53.1	54.4	1.8
19.5	20.2	20.9	21.6	22.3	23.0	23.7	1.1	Chest circ.	18.8	19.5	20.2	21.0	21.8	22.5	23.3	1.1
49.6	51.4	53.1	54.9	56.7	58.4	60.2	2.7		47.7	49.6	51.4	53.4	55.4	57.2	59.1	2.9
5.7	6.1	6.3	6.6	6.9	7.2	7.5	0.4	Upper arm circ.	5.8	6.1	6.5	6.8	7.1	7.4	7.7	0.5
14.6	15.4	16.1	16.8	17.5	18.2	19.0	1.1		14.8	15.6	16.4	17.2	18.0	18.8	19.6	1.2
3.0	3.5	4.1	4.6	5.2	5.7	6.3	0.8	Wrist circ.	3.5	3.8	4.1	4.5	4.8	5.2	5.5	0.5
7.5	9.0	10.3	11.7	13.1	14.4	15.9	2.1		8.8	9.7	10.5	11.4	12.3	13.1	14.0	1.3
7.2	7.8	8.3	9.0	9.6	10.2	10.8	0.9	Calf circ.	7.8	8.2	8.6	9.0	9.4	9.8	10.3	0.6
18.2	19.8	21.2	22.8	24.4	25.8	27.4	2.3		19.7	20.8	21.8	22.9	24.0	25.0	26.1	1.6
								6½ years								
37.7	41.4	45.0	48.7	52.5	56.0	59.7	5.6	Weight	32.8	38.1	42.8	48.1	53.4	58.0	63.3	7.7
17.1	18.8	20.4	22.1	23.8	25.4	27.1	2.53		14.9	17.3	19.4	21.8	24.2	26.3	28.7	3.5
43.1	44.5	45.7	47.0	48.4	49.6	50.9	2.0	Height	42.6	44.1	45.5	46.9	48.4	49.7	51.2	2.2
109.6	113.0	116.1	119.5	122.9	126.0	129.4	5.0		108.3	112.1	115.5	119.2	122.9	126.3	130.1	5.5
22.4	23.3	24.0	24.9	25.7	26.5	27.4	1.3	Sitting height	22.2	23.1	23.8	24.6	25.5	26.2	27.0	1.2
56.9	59.1	61.0	63.2	65.4	67.3	69.5	3.2		56.5	58.6	60.5	62.6	64.7	66.6	68.7	3.1
8.5	9.3	9.8	10.3	10.8	11.3	11.5	0.7	Shoulder width	8.5	9.1	9.6	10.2	10.8	11.3	12.0	0.9
21.7	23.7	24.9	26.2	27.5	28.7	29.3	1.9		21.6	23.2	24.5	26.0	27.5	28.8	30.4	2.2
6.5	7.0	7.5	8.1	8.6	9.1	9.6	0.8	Pelvic width	6.7	7.2	7.6	8.1	8.6	9.0	9.5	0.7
16.5	17.9	19.1	20.5	21.9	23.1	24.5	2.0		17.0	18.3	19.4	20.6	21.8	22.9	24.2	1.8
18.3	18.9	19.6	20.3	21.0	21.6	22.3	1.0	Head circ.	18.4	19.0	19.5	20.1	20.6	21.1	21.7	0.8
46.4	48.1	49.7	51.5	53.3	54.9	56.6	2.6		46.8	48.3	49.6	51.0	52.4	53.7	55.2	2.1
19.9	20.6	21.2	21.9	22.6	23.3	23.9	1.0	Chest circ.	18.8	19.6	20.5	21.3	22.2	23.0	23.9	1.3
50.6	52.3	53.9	55.7	57.5	59.1	60.8	2.6		47.7	49.9	52.0	54.2	56.4	58.5	60.7	3.3
5.8	6.1	6.4	6.7	7.0	7.2	7.6	0.4	Upper arm circ.	5.8	6.2	6.5	6.9	7.3	7.6	8.0	0.6
14.8	15.6	16.3	17.0	17.7	18.4	19.2	1.1		14.7	15.7	16.5	17.5	18.5	19.3	20.3	1.4
3.3	3.8	4.2	4.7	5.2	5.6	6.1	0.7	Wrist circ.	3.8	4.1	4.3	4.6	4.8	5.1	5.4	0.4
8.3	9.6	10.7	11.9	13.1	14.2	15.5	1.8		9.6	10.3	10.9	11.6	12.3	12.9	13.6	1.0
7.4	8.0	8.5	9.2	9.8	10.4	11.0	0.9	Calf circ.	8.0	8.4	8.8	9.2	9.6	10.0	10.5	0.6
[illegible]	[illegible]	[illegible]	23.3	24.9	26.3	27.9	2.3		20.2	21.3	22.3	23.4	24.5	25.5	26.6	1.6

Normal Measurements During Growth – 7 Years to 8 Years'

Weight in pounds and *kilogrammes*, other measurements in inches and *centimetres* (P = percentile)

Boys P_{10}	Boys P_{25}	Boys P_{50}	Boys P_{75}	Boys P_{90}	Boys $P_{97.5}$	Boys s		Girls $P_{2.5}$	Girls P_{10}	Girls P_{25}	Girls P_{50}	Girls P_{75}	Girls P_{90}	Girls $P_{97.5}$	Girls s
							7 years								
43.7	47.2	51.1	55.1	58.6	62.6	5.8	Weight	34.8	40.6	45.9	51.8	57.8	63.1	68.8	8.6
19.8	*21.4*	*23.2*	*25.0*	*26.6*	*28.4*	*2.61*		*15.8*	*18.4*	*20.8*	*23.5*	*26.2*	*28.6*	*31.2*	*3.9*
45.6	46.8	48.2	49.6	50.8	52.2	2.0	Height	43.9	45.4	46.7	48.2	49.6	51.0	52.5	2.2
115.8	*118.9*	*122.4*	*125.9*	*129.0*	*132.5*	*5.1*		*111.5*	*115.3*	*118.7*	*122.4*	*126.1*	*129.5*	*133.3*	*5.5*
23.7	24.5	25.3	26.1	26.8	27.6	1.2	Sitting height	22.7	23.5	24.3	25.1	25.9	26.7	27.5	1.2
60.3	*62.2*	*64.2*	*66.2*	*68.1*	*70.1*	*3.0*		*57.6*	*59.7*	*61.6*	*63.7*	*65.8*	*67.7*	*69.8*	*3.1*
9.6	10.1	10.6	11.0	11.5	11.7	0.7	Shoulder width	8.8	9.4	9.9	10.5	11.1	11.6	12.2	0.9
24.5	*25.6*	*26.8*	*28.0*	*29.1*	*29.8*	*1.8*		*22.3*	*23.9*	*25.2*	*26.7*	*28.2*	*29.5*	*31.1*	*2.2*
7.2	7.7	8.2	8.7	9.2	9.7	0.7	Pelvic width	6.9	7.4	7.8	8.3	8.7	9.2	9.7	0.7
18.4	*19.6*	*20.9*	*22.2*	*23.4*	*24.7*	*1.9*		*17.4*	*18.7*	*19.8*	*21.0*	*22.2*	*23.3*	*24.6*	*1.8*
18.9	19.6	20.3	21.0	21.7	22.4	1.1	Head circ.	18.5	19.1	19.6	20.2	20.7	21.2	21.8	0.8
48.1	*49.8*	*51.6*	*53.4*	*55.1*	*56.9*	*2.7*		*47.0*	*48.5*	*49.8*	*51.2*	*52.6*	*53.9*	*55.4*	*2.1*
20.9	21.5	22.2	23.0	23.6	24.3	1.1	Chest circ.	19.0	20.0	20.8	21.7	22.7	23.5	24.4	1.4
53.0	*54.7*	*56.5*	*58.3*	*60.0*	*61.8*	*2.7*		*48.3*	*50.7*	*52.8*	*55.2*	*57.6*	*59.7*	*62.1*	*3.5*
6.1	6.5	6.8	7.1	7.4	7.7	0.5	Upper arm circ.	5.7	6.2	6.6	7.0	7.4	7.8	8.3	0.6
15.6	*16.4*	*17.2*	*18.0*	*18.8*	*19.6*	*1.2*		*14.6*	*15.7*	*16.7*	*17.8*	*18.9*	*19.9*	*21.0*	*1.6*
3.9	4.3	4.8	5.2	5.6	6.0	0.6	Wrist circ.	3.7	4.0	4.3	4.7	5.0	5.4	5.7	0.5
10.0	*11.0*	*12.1*	*13.2*	*14.2*	*15.3*	*1.6*		*9.3*	*10.2*	*11.0*	*11.9*	*12.8*	*13.6*	*14.5*	*1.3*
8.1	8.7	9.3	10.0	10.5	11.1	0.9	Calf circ.	8.1	8.6	9.0	9.5	10.0	10.4	10.9	0.7
20.7	*22.1*	*23.7*	*25.3*	*26.7*	*28.3*	*2.3*		*20.5*	*21.8*	*22.9*	*24.1*	*25.3*	*26.4*	*27.7*	*1.8*
							7½ years								
45.0	48.9	53.6	58.2	62.2	66.8	6.7	Weight	36.8	43.2	49.2	55.6	61.9	67.9	74.3	9.5
20.4	*22.2*	*24.3*	*26.4*	*28.2*	*30.3*	*3.05*		*16.7*	*19.6*	*22.3*	*25.2*	*28.1*	*30.8*	*33.7*	*4.3*
46.7	47.9	49.3	50.7	51.9	53.3	2.0	Height	45.2	46.7	48.0	49.4	50.8	52.1	53.5	2.1
118.6	*121.7*	*125.2*	*128.7*	*131.8*	*135.3*	*5.1*									*5.3*
24.1	24.9	25.7	26.5	27.2	28.0	1.2	Sitting height								1.1
61.3	*63.2*	*65.2*	*67.2*	*69.1*	*71.1*	*3.0*									*2.9*
9.9	10.4	10.8	11.3	11.7	12.0	0.7	Shoulder width								0.7
25.2	*26.3*	*27.5*	*28.7*	*29.8*	*30.4*	*1.8*									*1.9*
7.4	7.9	8.3	8.8	9.3	9.8	0.7	Pelvic width	7.1	7.6	8.0	8.5	8.9	9.3	9.8	0.7
18.9	*20.0*	*21.2*	*22.4*	*23.5*	*24.8*	*1.8*		*18.1*	*19.3*	*20.3*	*21.5*	*22.7*	*23.7*	*24.9*	*1.7*
19.0	19.6	20.4	21.1	21.7	22.4	1.1	Head circ.	18.6	19.2	19.7	20.2	20.8	21.3	21.9	0.8
48.2	*49.9*	*51.7*	*53.5*	*55.2*	*57.0*	*2.7*		*47.2*	*48.7*	*50.0*	*51.4*	*52.8*	*54.1*	*55.6*	*2.1*
21.1	21.8	22.6	23.3	24.1	24.8	1.1	Chest circ.	19.3	20.2	21.1	22.1	23.1	24.0	25.0	1.5
53.5	*55.3*	*57.3*	*59.3*	*61.1*	*63.0*	*2.9*		*48.9*	*51.4*	*53.7*	*56.2*	*58.7*	*61.0*	*63.5*	*3.7*
6.2	6.5	6.9	7.3	7.6	8.0	0.6	Upper arm circ.	5.7	6.3	6.7	7.2	7.6	8.1	8.6	0.7
15.7	*16.5*	*17.5*	*18.5*	*19.3*	*20.3*	*1.4*		*14.6*	*15.9*	*17.0*	*18.2*	*19.4*	*20.5*	*21.8*	*1.8*
4.1	4.4	4.8	5.2	5.6	5.9	0.6	Wrist circ.	3.3	3.8	4.3	4.8	5.4	5.9	6.4	0.8
10.5	*11.3*	*12.3*	*13.3*	*14.1*	*15.1*	*1.4*		*8.3*	*9.7*	*10.9*	*12.3*	*13.7*	*14.9*	*16.3*	*2.0*
8.3	8.9	9.5	10.2	10.7	11.3	0.9	Calf circ.	8.3	8.8	9.3	9.8	10.4	10.9	11.4	0.8
21.2	*22.6*	*24.2*	*25.8*	*27.2*	*28.8*	*2.3*		*21.0*	*22.4*	*23.6*	*25.0*	*26.4*	*27.6*	*29.0*	*2.0*
							8 years								
45.9	50.5	55.8	61.1	65.7	71.0	7.7	Weight	38.8	45.6	52.0	58.9	65.7	72.1	78.9	10.1
20.8	*22.9*	*25.3*	*27.7*	*29.8*	*32.2*	*3.49*		*17.6*	*20.7*	*23.6*	*26.7*	*29.8*	*32.7*	*35.8*	*4.6*
47.8	49.0	50.4	51.8	53.0	54.4	2.0	Height	46.6	47.9	49.1	50.5	51.8	53.0	54.4	2.0
121.3	*124.5*	*128.0*	*131.5*	*134.7*	*138.3*	*5.2*		*118.3*	*121.7*	*124.8*	*128.2*	*131.6*	*134.7*	*138.1*	*5.0*
24.4	25.2	26.1	26.9	27.7	28.5	1.3	Sitting height	23.8	24.5	25.2	25.9	26.7	27.4	28.1	1.1
62.1	*64.0*	*66.2*	*68.4*	*70.3*	*72.5*	*3.2*		*60.4*	*62.3*	*64.0*	*65.9*	*67.8*	*69.5*	*71.4*	*2.8*
10.2	10.6	11.1	11.5	11.9	12.2	0.7	Shoulder width	9.7	10.2	10.6	11.0	11.5	11.9	12.4	0.7
25.9	*26.9*	*28.1*	*29.3*	*30.3*	*30.9*	*1.7*		*24.6*	*25.8*	*26.8*	*28.0*	*29.2*	*30.2*	*31.4*	*1.7*
7.8	8.1	8.5	8.9	9.3	9.7	0.6	Pelvic width	7.4	7.8	8.2	8.6	9.1	9.4	9.8	0.6
19.7	*20.6*	*21.6*	*22.6*	*23.5*	*24.6*	*1.5*		*18.8*	*19.8*	*20.8*	*21.9*	*23.0*	*24.0*	*25.0*	*1.6*
19.0	19.7	20.4	21.1	21.8	22.5	1.1	Head circ.	18.5	19.1	19.6	20.3	20.9	21.5	22.1	0.9
48.3	*50.0*	*51.8*	*53.6*	*55.3*	*57.1*	*2.7*		*46.9*	*48.5*	*49.9*	*51.5*	*53.1*	*54.5*	*56.1*	*2.3*
21.3	22.0	22.9	23.7	24.4	25.3	1.2	Chest circ.	19.4	20.5	21.4	22.5	23.5	24.5	25.5	1.5
54.1	*55.0*	*58.1*	*60.2*	*62.1*	*64.2*	*3.1*		*49.4*	*52.0*	*54.4*	*57.1*	*59.8*	*62.2*	*64.8*	*3.9*
6.3	6.6	7.0	7.4	7.8	8.2	0.6	Upper arm circ.	5.7	6.3	6.7	7.3	7.8	8.3	8.9	0.8
15.9	*16.8*	*17.8*	*18.8*	*19.7*	*20.8*	*1.5*		*14.5*	*15.9*	*17.1*	*18.5*	*19.9*	*21.1*	*22.5*	*2.0*
4.3	4.6	4.9	5.3	5.6	5.9	0.5	Wrist circ.	3.4	3.9	4.4	5.0	5.5	6.0	6.5	0.8
10.8	*11.6*	*12.5*	*13.4*	*14.2*	*15.1*	*1.3*		*8.6*	*10.0*	*11.2*	*12.6*	*14.0*	*15.2*	*16.6*	*2.0*
8.5	9.1	9.7	10.4	10.9	11.5	0.9	Calf circ.	8.3	9.0	9.5	10.1	10.7	11.2	11.8	[illegible]
21.7	*23.1*	*24.7*	*26.3*	*27.7*	*29.3*	*2.3*		*21.2*	*22.8*	*24.1*	*25.6*	*27.1*	*28.4*	*30.0*	*2.2*

Normal Measurements During Growth – 8½ Years to 9½ Years[1]

Weight in pounds and *kilogrammes*; other measurements in inches and *centimetres* (*P* = percentile)

Boys $P_{2.5}$	Boys P_{10}	Boys P_{25}	Boys P_{50}	Boys P_{75}	Boys P_{90}	Boys $P_{97.5}$	Boys *s*		Girls $P_{2.5}$	Girls P_{10}	Girls P_{25}	Girls P_{50}	Girls P_{75}	Girls P_{90}	Girls $P_{97.5}$	Girls *s*
								8½ years								
39.0	45.6	51.6	58.2	64.8	70.8	77.4	9.6	Weight	40.3	47.6	54.0	61.3	68.6	75.0	82.2	[illegible]
17.7	*20.7*	*23.4*	*26.4*	*29.4*	*32.1*	*35.1*	*4.37*		*18.3*	*21.6*	*24.5*	*27.8*	*31.1*	*34.0*	*37.3*	[illegible]
47.5	48.9	50.1	51.5	52.8	54.1	55.4	2.0	Height	47.5	48.9	50.1	51.5	52.9	54.1	55.5	[illegible]
120.6	*124.1*	*127.2*	*130.7*	*134.2*	*137.3*	*140.8*	*5.1*		*120.7*	*124.2*	*127.3*	*130.8*	*134.3*	*137.4*	*140.9*	[illegible]
23.8	24.7	25.6	26.5	27.4	28.2	29.1	1.3	Sitting height	24.3	25.0	25.7	26.4	27.1	27.8	28.5	[illegible]
60.5	*62.8*	*64.9*	*67.2*	*69.5*	*71.6*	*73.9*	*3.4*		*61.7*	*63.5*	*65.2*	*67.0*	*68.8*	*70.5*	*72.3*	[illegible]
9.8	10.5	10.9	11.3	11.7	12.1	12.3	0.6	Shoulder width	9.9	10.4	10.8	11.3	11.7	12.1	12.6	[illegible]
24.9	*26.6*	*27.6*	*28.7*	*29.8*	*30.8*	*31.3*	*1.6*		*25.2*	*26.4*	*27.4*	*28.6*	*29.8*	*30.8*	*32.0*	[illegible]
7.6	8.0	8.3	8.7	9.0	9.3	9.7	0.5	Pelvic width	7.6	8.0	8.3	8.8	9.2	9.6	10.0	[illegible]
19.4	*20.3*	*21.1*	*22.0*	*22.9*	*23.7*	*24.6*	*1.3*		*19.2*	*20.2*	*21.2*	*22.3*	*23.4*	*24.4*	*25.4*	[illegible]
18.3	19.0	19.7	20.4	21.2	21.9	22.6	1.1	Head circ.	18.1	18.9	19.6	20.3	21.1	21.7	22.5	[illegible]
46.4	*48.3*	*50.0*	*51.9*	*53.8*	*55.5*	*57.4*	*2.8*		*46.1*	*48.0*	*49.7*	*51.6*	*53.5*	*55.2*	*57.1*	[illegible]
20.7	21.6	22.4	23.2	24.1	24.8	25.7	1.3	Chest circ.	19.5	20.7	21.7	22.8	23.9	24.9	26.1	[illegible]
52.7	*54.9*	*56.8*	*59.0*	*61.2*	*63.1*	*65.3*	*3.2*		*49.6*	*52.5*	*55.0*	*57.9*	*60.8*	*63.3*	*66.2*	[illegible]
5.9	6.4	6.7	7.1	7.5	7.9	8.3	0.6	Upper arm circ.	5.7	6.3	6.9	7.4	8.0	8.5	9.1	[illegible]
15.1	*16.2*	*17.1*	*18.1*	*19.1*	*20.0*	*21.1*	*1.5*		*14.6*	*16.1*	*17.4*	*18.8*	*20.2*	*21.5*	*23.0*	[illegible]
4.0	4.3	4.6	5.0	5.4	5.7	6.0	0.5	Wrist circ.	3.7	4.1	4.5	5.0	5.5	5.9	6.3	[illegible]
10.1	*11.0*	*11.8*	*12.7*	*13.6*	*14.4*	*15.3*	*1.3*		*9.3*	*10.5*	*11.5*	*12.7*	*13.9*	*14.9*	*16.1*	[illegible]
8.1	8.7	9.3	9.9	10.6	11.1	11.7	0.9	Calf circ.	8.4	9.0	9.6	10.2	10.8	11.4	12.0	[illegible]
20.6	*22.2*	*23.6*	*25.2*	*26.8*	*28.2*	*29.8*	*2.3*		*21.3*	*22.9*	*24.3*	*25.9*	*27.5*	*28.9*	*30.5*	[illegible]
								9 years								
41.2	47.8	54.0	60.6	67.2	73.4	80.0	9.8	Weight	42.5	49.8	56.2	63.5	70.8	77.2	84.4	[illegible]
18.7	*21.7*	*24.5*	*27.5*	*30.5*	*33.3*	*36.3*	*4.46*		*19.3*	*22.6*	*25.5*	*28.8*	*32.1*	*35.0*	*38.3*	[illegible]
48.5	49.9	51.1	52.5	53.9	55.1	56.5	2.0	Height	48.4	49.8	51.1	52.4	53.8	55.1	56.5	[illegible]
123.2	*126.7*	*129.8*	*133.3*	*136.8*	*139.9*	*143.4*	*5.1*		*122.9*	*126.5*	*129.7*	*133.2*	*136.7*	*139.9*	*143.5*	[illegible]
23.9	24.9	25.8	26.8	27.8	28.7	29.7	1.5	Sitting height	24.4	25.2	25.9	26.8	27.6	28.3	29.2	[illegible]
60.8	*63.3*	*65.6*	*68.1*	*70.6*	*72.9*	*75.4*	*3.7*		*61.9*	*64.0*	*65.9*	*68.0*	*70.1*	*72.0*	*74.1*	[illegible]
10.0	10.7	11.1	11.5	12.0	12.4	12.6	0.6	Shoulder width	10.0	10.6	11.0	11.5	11.9	12.4	12.9	[illegible]
25.5	*27.2*	*28.2*	*29.3*	*30.4*	*31.4*	*31.9*	*1.6*		*25.5*	*26.8*	*27.9*	*29.1*	*30.3*	*31.4*	*32.7*	[illegible]
7.9	8.2	8.5	8.8	9.1	9.4	9.8	0.5	Pelvic width	7.7	8.1	8.5	8.9	9.4	9.8	10.2	[illegible]
20.0	*20.8*	*21.6*	*22.4*	*23.2*	*24.0*	*24.8*	*1.2*		*19.6*	*20.6*	*21.6*	*22.7*	*23.8*	*24.8*	*25.8*	[illegible]
18.3	19.1	19.7	20.5	21.2	21.9	22.6	1.1	Head circ.	17.8	18.7	19.5	20.4	21.3	22.1	23.0	1.3
46.5	*48.4*	*50.1*	*52.0*	*53.9*	*55.6*	*57.5*	*2.8*		*45.1*	*47.4*	*49.5*	*51.8*	*54.1*	*56.2*	*58.5*	[illegible]
21.2	22.1	22.8	23.7	24.6	25.3	26.2	1.3	Chest circ.	19.3	20.6	21.8	23.1	24.4	25.6	26.9	1.9
53.9	*56.1*	*58.0*	*60.2*	*62.4*	*64.3*	*66.5*	*3.2*		*48.9*	*52.3*	*55.3*	*58.6*	*61.9*	*64.9*	*68.3*	*4.9*
6.1	6.5	6.9	7.2	7.6	8.0	8.3	0.6	Upper arm circ.	5.8	6.4	6.9	7.5	8.1	8.6	9.3	0.9
15.6	*16.6*	*17.4*	*18.4*	*19.4*	*20.2*	*21.2*	*1.4*		*14.7*	*16.3*	*17.6*	*19.1*	*20.6*	*21.9*	*23.5*	*2.2*
4.1	4.4	4.8	5.1	5.4	5.7	6.0	0.5	Wrist circ.	3.9	4.3	4.6	5.0	5.4	5.7	6.1	0.6
10.5	*11.3*	*12.1*	*12.9*	*13.7*	*14.5*	*15.3*	*1.2*		*9.9*	*10.9*	*11.7*	*12.7*	*13.7*	*14.5*	*15.5*	*1.4*
8.3	8.9	9.4	10.1	10.7	11.3	11.9	0.9	Calf circ.	8.4	9.1	9.7	10.3	10.9	11.5	12.2	0.9
21.0	*22.6*	*24.0*	*25.6*	*27.2*	*28.6*	*30.2*	*2.3*		*21.4*	*23.1*	*24.6*	*26.2*	*27.8*	*29.3*	*31.0*	*2.4*
								9½ years								
41.9	49.2	55.8	63.1	70.3	76.9	84.2	10.7	Weight	45.2	52.5	58.9	66.1	73.4	79.8	87.1	10.6
19.0	*22.3*	*25.3*	*28.6*	*31.9*	*34.9*	*38.2*	*4.86*		*20.5*	*23.8*	*26.7*	*30.0*	*33.3*	*36.2*	*39.5*	*4.8*
49.3	50.7	52.0	53.5	54.9	56.2	57.6	2.1	Height	49.1	50.6	51.9	53.3	54.8	56.1	57.5	2.1
125.3	*128.9*	*132.2*	*135.8*	*139.4*	*142.7*	*146.3*	*5.3*		*124.7*	*128.4*	*131.7*	*135.4*	*139.1*	*142.4*	*146.1*	*5.4*
24.0	25.1	26.1	27.2	28.3	29.3	30.4	1.6	Sitting height	24.0	25.1	26.1	27.2	28.3	29.3	30.4	1.6
61.0	*63.8*	*66.3*	*69.1*	*71.9*	*74.4*	*77.2*	*4.1*		*61.0*	*63.8*	*66.3*	*69.1*	*71.9*	*74.4*	*77.2*	*4.1*
10.5	10.9	11.3	11.8	12.2	12.6	13.0	0.6	Shoulder width	10.1	10.6	11.1	11.6	12.1	12.6	13.1	0.7
26.7	*27.8*	*28.8*	*29.9*	*31.0*	*32.0*	*33.1*	*1.6*		*25.7*	*27.0*	*28.2*	*29.5*	*30.8*	*32.0*	*33.3*	*1.9*
8.0	8.3	8.6	9.0	9.3	9.6	10.0	0.5	Pelvic width	7.9	8.3	8.7	9.1	9.5	9.9	10.3	0.6
20.2	*21.1*	*21.9*	*22.8*	*23.7*	*24.5*	*25.4*	*1.3*		*20.0*	*21.0*	*22.0*	*23.1*	*24.2*	*25.2*	*26.2*	*1.6*
18.3	19.1	19.8	20.5	21.3	21.9	22.7	1.1	Head circ.	17.5	18.5	19.4	20.4	21.5	22.4	23.4	1.5
46.6	*48.5*	*50.2*	*52.1*	*54.0*	*55.7*	*57.6*	*2.8*		*44.4*	*47.0*	*49.3*	*51.9*	*54.5*	*56.8*	*59.4*	*3.8*
21.7	22.5	23.3	24.1	25.0	25.7	26.6	1.3	Chest circ.	19.1	20.6	21.9	23.4	24.8	26.2	27.7	2.2
55.0	*57.2*	*59.1*	*61.3*	*63.5*	*65.4*	*67.6*	*3.2*		*48.5*	*52.3*	*55.7*	*59.4*	*63.1*	*66.5*	*70.3*	*5.5*
6.3	6.7	7.0	7.4	7.8	8.1	8.5	0.6	Upper arm circ.	5.8	6.5	7.0	7.6	8.3	8.8	9.4	0.9
15.9	*16.9*	*17.7*	*18.7*	*19.7*	*20.5*	*21.5*	*1.4*		*14.8*	*16.4*	*17.8*	*19.4*	*21.0*	*22.4*	*24.0*	*2.3*
4.2	4.5	4.8	5.2	5.5	5.8	6.1	0.5	Wrist circ.	3.9	4.3	4.7	5.1	5.5	5.8	6.3	0.6
10.7	*11.5*	*12.3*	*13.1*	*13.9*	*14.7*	*15.5*	*1.2*		*9.9*	*11.0*	*11.9*	*12.9*	*13.9*	*14.8*	*15.9*	*1.5*
8.5	9.1	9.6	10.3	10.9	11.5	12.1	0.9	Calf circ.	8.6	9.3	9.8	10.5	11.1	11.7	12.4	0.9
21.5	*23.1*	*24.5*	*26.1*	*27.7*	*29.1*	*30.7*	*2.3*		*21.8*	*23.5*	*25.0*	*26.6*	*28.2*	*29.7*	*31.4*	*2.4*

(Brackets above the percentile columns, for both boys and girls: 50% spans P_{25}–P_{75}; 80% spans P_{10}–P_{90}; 95% spans $P_{2.5}$–$P_{97.5}$.)

[1] HEIMENDINGER, J., *Helv. paediat. Acta*, 19, suppl. 13 (1964). From measurements made in the period 1956–1957 on 2150 boys and 2150 girls in Basle.

Weight in pounds and *kilogrammes*, other measurements in inches and *centimetres* (P = percentile)

Boys									Girls							
	95%									95%						
		80%									80%					
			50%									50%				
P_3	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{97}	σ		P_3	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{97}	σ
								10 years								
9	51.8	59.1	67.2	75.4	82.7	90.6	11.8	Weight	46.7	54.7	61.7	69.4	77.2	84.2	92.2	11.5
9	*23.5*	*26.8*	*30.5*	*34.2*	*37.5*	*41.1*	*5.37*		*21.2*	*24.8*	*28.0*	*31.5*	*35.0*	*38.2*	*41.8*	*5.2*
2	51.7	53.0	54.4	55.9	57.2	58.7	2.2	Height	49.8	51.3	52.6	54.1	55.6	57.0	58.5	2.2
.4	*131.2*	*134.6*	*138.3*	*142.0*	*145.4*	*149.2*	*5.5*									*5.6*
9	25.2	26.3	27.6	28.9	30.0	31.3	1.9	Sitting height								1.9
8	*64.0*	*66.9*	*70.1*	*73.3*	*76.2*	*79.4*	*4.7*									*4.8*
7	11.2	11.6	12.0	12.4	12.8	13.3	0.6	Shoulder width								0.8
73	*28.4*	*29.4*	*30.5*	*31.6*	*32.6*	*33.7*	*1.6*									*2.0*
31	8.5	8.7	9.2	9.2	9.9	10.3	0.6	Pelvic width								0.7
5	*21.5*	*22.2*	*23.3*	*23.4*	*25.1*	*26.1*	*1.4*		*20.2*	*21.4*	*22.4*	*23.6*	*24.8*	*25.8*	*27.0*	*1.7*
4	19.2	19.8	20.6	21.3	22.0	22.8	1.1	Head circ.	17.3	18.4	19.4	20.5	21.6	22.6	23.7	1.6
68	*49.7*	*50.4*	*52.3*	*54.2*	*55.9*	*57.8*	*2.8*		*43.9*	*46.7*	*49.2*	*52.0*	*54.8*	*57.3*	*60.1*	*4.1*
19	22.8	23.6	24.5	25.4	26.2	27.1	1.3	Chest circ	19.1	20.7	22.1	23.7	25.2	26.6	28.2	2.3
5.5	*57.8*	*59.9*	*62.2*	*64.5*	*66.6*	*68.9*	*3.4*		*48.6*	*52.6*	*56.1*	*60.1*	*64.1*	*67.6*	*71.6*	*5.8*
6.3	6.8	7.1	7.5	7.9	8.3	8.7	0.6	Upper arm circ	5.8	6.5	7.1	7.8	8.5	9.1	9.8	1.0
6.1	*17.2*	*18.1*	*19.1*	*20.1*	*21.0*	*22.1*	*1.5*		*14.8*	*16.6*	*18.1*	*19.8*	*21.5*	*23.0*	*24.8*	*2.5*
4.2	4.6	4.9	5.2	5.6	5.9	6.3	0.5	Wrist circ	3.3	3.9	4.5	5.2	5.8	6.4	7.0	0.9
0.7	*11.6*	*12.4*	*13.3*	*14.2*	*15.0*	*15.9*	*1.3*		*8.3*	*10.0*	*11.5*	*13.1*	*14.7*	*16.2*	*17.9*	*2.4*
8.7	9.3	9.8	10.5	11.1	11.7	12.3	0.9	Calf circ	8.7	9.4	10.0	10.7	11.3	11.9	12.6	1.0
20	*23.6*	*25.0*	*26.6*	*28.2*	*29.6*	*31.2*	*2.3*		*22.1*	*23.9*	*25.4*	*27.1*	*28.8*	*30.3*	*32.1*	*2.5*
								10½ years								
5.4	54.7	62.8	72.1	81.3	89.5	98.8	13.4	Weight	47.0	56.0	63.9	72.8	81.6	89.5	98.5	13.0
20.6	*24.8*	*28.5*	*32.7*	*36.9*	*40.6*	*44.8*	*6.10*		*21.3*	*25.4*	*29.0*	*33.0*	*37.0*	*40.6*	*44.7*	*5.9*
50.8	52.4	53.8	55.4	56.9	58.3	59.9	2.3	Height	50.2	51.8	53.3	54.9	56.6	58.0	59.7	2.4
129.1	*133.1*	*136.6*	*140.6*	*144.6*	*148.1*	*152.1*	*5.8*		*127.4*	*131.6*	*135.3*	*139.5*	*143.7*	*147.4*	*151.6*	*6.1*
24.1	25.4	26.7	28.0	29.3	30.6	31.9	2.0	Sitting height	24.0	25.4	26.7	28.1	29.4	30.7	32.1	2.0
61.2	*64.6*	*67.7*	*71.1*	*74.5*	*77.6*	*81.0*	*5.0*		*61.0*	*64.6*	*67.8*	*71.3*	*74.8*	*78.0*	*81.6*	*5.2*
10.9	11.4	11.8	12.2	12.7	13.1	13.6	0.7	Shoulder width	10.3	10.9	11.4	12.0	12.6	13.1	13.7	0.8
27.7	*28.9*	*29.9*	*31.1*	*32.3*	*33.3*	*34.5*	*1.7*		*26.2*	*27.7*	*29.0*	*30.5*	*32.0*	*33.3*	*34.8*	*2.1*
8.1	8.5	8.9	9.3	9.8	10.2	10.6	0.6	Pelvic width	8.0	8.5	9.0	9.4	9.9	10.4	10.9	0.7
20.5	*21.6*	*22.6*	*23.7*	*24.8*	*25.8*	*26.9*	*1.6*		*20.4*	*21.7*	*22.8*	*24.0*	*25.2*	*26.3*	*27.6*	*1.8*
18.6	19.3	19.9	20.6	21.3	22.0	22.6	1.0	Head circ	17.4	18.5	19.4	20.6	21.7	22.6	23.7	1.6
47.3	*49.0*	*50.6*	*52.4*	*54.2*	*55.8*	*57.5*	*2.6*		*44.1*	*46.9*	*49.4*	*52.2*	*55.0*	*57.5*	*60.3*	*4.1*
21.8	22.8	23.7	24.7	25.7	26.7	27.7	1.5	Chest circ	19.3	20.9	22.4	24.0	25.6	27.0	28.7	2.4
55.3	*57.9*	*60.2*	*62.8*	*65.4*	*67.7*	*70.3*	*3.8*		*49.0*	*53.1*	*56.8*	*60.9*	*65.0*	*68.7*	*72.8*	*6.0*
6.3	6.8	7.2	7.7	8.1	8.5	9.0	0.7	Upper arm circ	5.9	6.6	7.2	7.9	8.6	9.3	9.9	1.0
16.1	*17.3*	*18.3*	*19.5*	*20.7*	*21.7*	*22.9*	*1.7*		*15.0*	*16.7*	*18.3*	*20.1*	*21.9*	*23.5*	*25.2*	*2.6*
4.2	4.6	4.9	5.3	5.7	6.0	6.4	0.6	Wrist circ	3.2	3.9	4.6	5.3	6.0	6.7	7.4	1.1
10.7	*11.7*	*12.5*	*13.5*	*14.5*	*15.3*	*16.3*	*1.4*		*8.1*	*9.9*	*11.6*	*13.4*	*15.2*	*16.9*	*18.7*	*2.7*
8.9	9.5	10.0	10.7	11.3	11.9	12.5	0.9	Calf circ	8.8	9.5	10.2	10.9	11.7	12.4	13.1	1.1
22.5	*24.1*	*25.5*	*27.1*	*28.7*	*30.1*	*31.7*	*2.3*		*22.3*	*24.2*	*25.9*	*27.8*	*29.7*	*31.4*	*33.3*	*2.8*
								11 years								
50.5	59.7	67.9	77.2	86.4	94.6	103.8	13.5	Weight	48.3	58.2	67.0	76.7	86.4	95.2	105.2	14.3
22.9	*27.1*	*30.8*	*35.0*	*39.2*	*42.9*	*47.1*	*6.12*		*21.9*	*26.4*	*30.4*	*34.8*	*39.2*	*43.2*	*47.7*	*6.5*
51.5	53.1	54.6	56.2	57.8	59.3	60.9	2.4	Height	50.7	52.5	54.1	55.8	57.6	59.1	60.9	2.6
130.8	*134.9*	*138.6*	*142.7*	*146.8*	*150.5*	*154.6*	*6.0*		*128.9*	*133.4*	*137.4*	*141.8*	*146.2*	*150.2*	*154.7*	*6.5*
24.3	25.7	27.0	28.4	29.8	31.0	32.4	2.0	Sitting height	24.3	25.7	27.0	28.5	30.0	31.3	32.7	2.1
61.8	*65.4*	*68.6*	*72.1*	*75.6*	*78.8*	*82.4*	*5.2*		*61.7*	*65.4*	*68.7*	*72.4*	*76.1*	*79.4*	*83.1*	*5.4*
10.9	11.5	11.9	12.4	13.0	13.4	13.9	0.7	Shoulder width	10.4	11.0	11.6	12.2	12.8	13.4	14.0	0.9
27.8	*29.1*	*30.3*	*31.6*	*32.9*	*34.1*	*35.4*	*1.9*		*26.4*	*28.0*	*29.4*	*31.0*	*32.6*	*34.0*	*35.6*	*2.3*
8.0	8.5	9.0	9.5	10.0	10.5	11.0	0.7	Pelvic width	8.1	8.7	9.1	9.6	10.2	10.6	11.1	0.7
20.3	*21.6*	*22.8*	*24.1*	*25.4*	*26.6*	*27.9*	*1.9*		*20.7*	*22.2*	*23.2*	*24.5*	*25.8*	*26.8*	*28.3*	*1.9*
18.9	19.6	20.1	20.7	21.3	21.8	22.4	0.9	Head circ	17.6	18.7	19.6	20.6	21.6	22.5	23.5	1.5
48.1	*49.7*	*51.0*	*52.5*	*54.0*	*55.3*	*56.9*	*2.2*		*44.8*	*47.4*	*49.7*	*52.3*	*54.9*	*57.2*	*59.8*	*3.8*
21.8	22.9	23.9	25.0	26.1	27.0	28.1	1.6	Chest circ	19.4	21.1	22.6	24.3	25.9	27.4	29.1	2.4
55.3	*58.1*	*60.6*	*63.4*	*66.2*	*68.7*	*71.5*	*4.1*		*49.3*	*53.6*	*57.4*	*61.6*	*65.8*	*69.6*	*73.9*	*6.2*
6.3	6.9	7.3	7.8	8.3	8.8	9.3	0.7	Upper arm circ	5.9	6.7	7.3	8.0	8.8	9.4	10.1	1.1
16.1	*17.4*	*18.6*	*19.9*	*21.2*	*22.4*	*23.7*	*1.9*		*15.1*	*16.9*	*18.5*	*20.4*	*22.3*	*23.9*	*25.7*	*2.7*
4.2	4.6	5.0	5.4	5.7	6.1	6.5	0.6	Wrist circ	3.9	4.4	4.8	5.3	5.8	6.2	6.7	0.7
10.6	*11.7*	*12.6*	*13.6*	*14.6*	*15.5*	*16.6*	*1.5*		*9.9*	*11.2*	*12.3*	*13.5*	*14.7*	*15.8*	*17.1*	*1.8*
9.0	9.6	10.2	10.8	11.5	12.0	12.6	0.9	Calf circ	8.9	9.6	10.3	11.1	11.8	12.5	13.2	1.1
22.9	*24.5*	*25.9*	*27.5*	*29.1*	*30.5*	*32.1*	*2.3*		*22.6*	*24.5*	*26.2*	*28.1*	*30.0*	*31.7*	*33.6*	*2.8*

Normal Measurements During Growth – 11½ Years to 12½ Years[1]

Weight in pounds and *kilogrammes*; other measurements in inches and *centimetres* (*P* = percentile)

Boys									Girls							
	95%									95%						
	80%									80%						
		50%									50%					
$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s		$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s
								11½ years								
53.6	63.5	72.3	82.2	92.2	101.0	110.9	14.5	Weight	50.5	61.1	70.5	81.1	91.7	101.2	111.8	15.4
24.3	*28.8*	*32.8*	*37.3*	*41.8*	*45.8*	*50.3*	*6.59*		*22.9*	*27.7*	*32.0*	*36.8*	*41.6*	*45.9*	*50.7*	*7.0*
52.0	53.7	55.2	57.0	58.7	60.2	62.0	2.5	Height	51.5	53.4	55.1	57.0	58.9	60.6	62.6	2.8
132.0	*136.4*	*140.3*	*144.7*	*149.1*	*153.0*	*157.4*	*6.4*		*130.7*	*135.6*	*140.0*	*144.8*	*149.6*	*154.0*	*158.9*	*7.1*
24.8	26.2	27.4	28.8	30.2	31.4	32.8	2.0	Sitting height	25.0	26.3	27.6	28.9	30.3	31.5	32.9	2.0
63.0	*66.5*	*69.6*	*73.1*	*76.6*	*79.7*	*83.2*	*5.1*		*63.4*	*66.9*	*70.0*	*73.5*	*77.0*	*80.1*	*83.6*	*5.1*
10.8	11.5	12.0	12.6	13.3	13.8	14.4	0.9	Shoulder width	10.6	11.2	11.8	12.4	13.1	13.7	14.3	0.9
27.5	*29.1*	*30.5*	*32.1*	*33.7*	*35.1*	*36.7*	*2.3*		*26.8*	*28.5*	*30.0*	*31.6*	*33.2*	*34.7*	*36.4*	*2.4*
7.8	8.5	9.1	9.7	10.3	10.9	11.6	0.9	Pelvic width	8.3	8.9	9.3	9.9	10.4	10.8	11.5	0.8
19.8	*21.5*	*23.0*	*24.6*	*26.2*	*27.7*	*29.4*	*2.4*		*21.1*	*22.7*	*23.7*	*25.1*	*26.5*	*27.5*	*29.1*	*2.0*
19.3	19.8	20.2	20.7	21.2	21.6	22.1	0.7	Head circ.	18.2	19.1	19.8	20.6	21.5	22.2	23.0	1.2
49.0	*50.3*	*51.4*	*52.6*	*53.8*	*54.9*	*56.2*	*1.8*		*46.3*	*48.4*	*50.3*	*52.4*	*54.5*	*56.4*	*58.5*	*3.1*
21.9	23.0	24.1	25.3	26.5	27.5	28.7	1.7	Chest circ.	19.7	21.4	22.9	24.6	26.2	27.7	29.4	2.4
55.5	*58.5*	*61.2*	*64.2*	*67.2*	*69.9*	*72.9*	*4.4*		*50.1*	*54.4*	*58.2*	*62.4*	*66.6*	*70.4*	*74.7*	*6.2*
6.2	6.8	7.4	8.0	8.6	9.2	9.8	0.9	Upper arm circ.	6.1	6.8	7.4	8.1	8.9	9.5	10.2	1.0
15.7	*17.3*	*18.7*	*20.3*	*21.9*	*23.3*	*24.9*	*2.3*		*15.5*	*17.3*	*18.9*	*20.7*	*22.5*	*24.1*	*25.9*	*2.6*
3.9	4.4	4.9	5.4	5.9	6.4	6.9	0.7	Wrist circ.	4.6	4.8	5.1	5.4	5.6	5.9	6.1	0.4
9.9	*11.2*	*12.4*	*13.7*	*15.0*	*16.2*	*17.5*	*1.9*		*11.6*	*12.3*	*12.9*	*13.6*	*14.3*	*14.9*	*15.6*	*1.0*
9.1	9.8	10.4	11.0	11.7	12.2	12.9	0.9	Calf circ.	8.9	9.7	10.4	11.2	12.0	12.7	13.4	1.1
23.2	*24.9*	*26.4*	*28.0*	*29.6*	*31.1*	*32.8*	*2.4*		*22.7*	*24.6*	*26.4*	*28.4*	*30.4*	*32.2*	*34.1*	*2.9*
								12 years								
56.9	67.5	76.7	87.1	97.4	106.7	117.3	15.2	Weight	53.6	64.8	75.0	86.0	97.0	107.1	118.4	16.3
25.8	*30.6*	*34.8*	*39.5*	*44.2*	*48.4*	*53.2*	*6.91*		*24.3*	*29.4*	*34.0*	*39.0*	*44.0*	*48.6*	*53.7*	*7.4*
52.6	54.4	56.1	57.9	59.7	61.3	63.2	2.7	Height	52.6	54.6	56.4	58.5	60.5	62.3	64.4	3.0
133.5	*138.2*	*142.4*	*147.0*	*151.6*	*155.8*	*160.5*	*6.8*		*133.5*	*138.7*	*143.3*	*148.5*	*153.7*	*158.3*	*163.5*	*7.6*
25.4	26.7	27.9	29.2	30.5	31.6	32.9	1.9	Sitting height	25.6	26.9	28.1	29.4	30.7	31.8	33.1	1.9
64.6	*67.9*	*70.8*	*74.1*	*77.4*	*80.3*	*83.6*	*4.8*		*65.1*	*68.4*	*71.3*	*74.6*	*77.9*	*80.8*	*84.1*	*4.8*
10.5	11.3	12.0	12.8	13.6	14.3	15.1	1.2	Shoulder width	10.7	11.5	12.0	12.7	13.4	14.0	14.7	1.0
26.6	*28.6*	*30.5*	*32.5*	*34.5*	*36.4*	*38.4*	*3.0*		*27.3*	*29.1*	*30.6*	*32.3*	*34.0*	*35.5*	*37.3*	*2.5*
7.6	8.4	9.1	9.9	10.7	11.4	12.1	1.1	Pelvic width	8.5	9.2	9.6	10.2	10.7	11.2	11.9	0.8
19.4	*21.3*	*23.1*	*25.1*	*27.1*	*28.9*	*30.8*	*2.9*		*21.7*	*23.4*	*24.5*	*25.9*	*27.3*	*28.4*	*30.1*	*2.1*
19.4	19.9	20.3	20.7	21.2	21.6	22.1	0.7	Head circ.	19.0	19.6	20.1	20.7	21.2	21.7	22.3	0.8
49.3	*50.5*	*51.5*	*52.7*	*53.9*	*54.9*	*56.1*	*1.7*		*48.3*	*49.8*	*51.1*	*52.5*	*53.9*	*55.2*	*56.7*	*2.1*
22.1	23.3	24.4	25.6	26.8	27.9	29.1	1.8	Chest circ.	19.9	21.6	23.1	24.8	26.5	28.1	29.8	2.5
56.1	*59.2*	*61.9*	*65.0*	*68.1*	*70.8*	*73.9*	*4.5*		*50.6*	*54.9*	*58.8*	*63.1*	*67.4*	*71.3*	*75.6*	*6.3*
6.0	6.7	7.4	8.1	8.9	9.6	10.3	1.1	Upper arm circ.	6.2	6.9	7.6	8.3	9.0	9.6	10.3	1.0
15.2	*17.1*	*18.8*	*20.7*	*22.6*	*24.3*	*26.2*	*2.8*		*15.8*	*17.6*	*19.2*	*21.0*	*22.8*	*24.4*	*26.2*	*2.6*
3.6	4.2	4.8	5.4	6.0	6.6	7.2	0.9	Wrist circ.	4.6	4.9	5.2	5.4	5.7	5.9	6.2	0.4
9.1	*10.7*	*12.1*	*13.7*	*15.3*	*16.7*	*18.3*	*2.3*		*11.8*	*12.5*	*13.1*	*13.8*	*14.5*	*15.1*	*15.8*	*1.0*
9.3	10.0	10.6	11.2	11.9	12.4	13.1	0.9	Calf circ.	9.1	9.8	10.5	11.3	12.1	12.8	13.5	1.1
23.7	*25.4*	*26.9*	*28.5*	*30.1*	*31.6*	*33.3*	*2.4*		*23.0*	*24.9*	*26.7*	*28.7*	*30.7*	*32.5*	*34.4*	*2.9*
								12½ years								
59.3	70.8	80.9	92.2	103.4	113.5	125.0	16.5	Weight	56.9	68.8	79.4	91.3	103.2	113.8	125.7	17.4
26.9	*32.1*	*36.7*	*41.8*	*46.9*	*51.5*	*56.7*	*7.50*		*25.8*	*31.2*	*36.0*	*41.4*	*46.8*	*51.6*	*57.0*	*7.9*
53.3	55.3	57.1	59.1	61.0	62.8	64.8	2.9	Height	53.7	55.7	57.6	59.6	61.7	63.6	65.6	3.0
135.3	*140.4*	*145.0*	*150.0*	*155.0*	*159.6*	*164.7*	*7.4*		*136.3*	*141.5*	*146.3*	*151.5*	*156.7*	*161.5*	*166.7*	*7.7*
26.1	27.3	28.4	29.6	30.7	31.8	33.0	1.7	Sitting height	26.5	27.6	28.7	29.8	30.9	32.0	33.1	1.7
66.4	*69.4*	*72.1*	*75.1*	*78.1*	*80.8*	*83.8*	*4.4*		*67.2*	*70.1*	*72.8*	*75.7*	*78.6*	*81.3*	*84.2*	*4.3*
9.5	10.7	11.7	12.9	14.0	15.1	16.2	1.7	Shoulder width	11.0	11.7	12.3	13.0	13.6	14.2	14.9	1.0
24.2	*27.1*	*29.8*	*32.7*	*35.6*	*38.3*	*41.2*	*4.3*		*27.9*	*29.7*	*31.2*	*32.9*	*34.6*	*36.1*	*37.9*	*2.5*
7.6	8.4	9.3	10.1	11.0	11.8	12.7	1.3	Pelvic width	8.8	9.5	10.0	10.6	11.1	11.6	12.3	0.9
19.2	*21.4*	*23.5*	*25.7*	*27.9*	*30.0*	*32.2*	*3.3*		*22.4*	*24.2*	*25.3*	*26.8*	*28.3*	*29.4*	*31.2*	*2.2*
19.5	20.0	20.4	20.8	21.2	21.6	22.0	0.6	Head circ.	19.4	19.9	20.3	20.7	21.2	21.6	22.1	0.7
49.6	*50.7*	*51.7*	*52.8*	*53.9*	*54.9*	*56.0*	*1.6*		*49.3*	*50.5*	*51.5*	*52.7*	*53.9*	*54.9*	*56.1*	*1.7*
22.3	23.6	24.8	26.1	27.4	28.5	29.8	1.9	Chest circ.	20.2	21.9	23.5	25.2	26.9	28.5	30.2	2.5
56.7	*60.0*	*62.9*	*66.2*	*69.5*	*72.4*	*75.7*	*4.8*		*51.3*	*55.7*	*59.6*	*64.0*	*68.4*	*72.3*	*76.6*	*6.4*
5.7	6.6	7.4	8.3	9.1	10.0	10.8	1.3	Upper arm circ.	6.3	7.0	7.7	8.4	9.1	9.7	10.4	1.0
14.5	*16.7*	*18.8*	*21.0*	*23.2*	*25.3*	*27.5*	*3.3*		*16.1*	*17.9*	*19.5*	*21.3*	*23.1*	*24.7*	*26.5*	*2.6*
3.5	4.2	4.8	5.4	6.1	6.7	7.4	1.0	Wrist circ.	4.8	5.0	5.3	5.6	5.8	6.1	6.3	0.4
8.8	*10.6*	*12.1*	*13.8*	*15.5*	*17.0*	*18.8*	*2.5*		*12.1*	*12.8*	*13.4*	*14.1*	*14.8*	*15.4*	*16.1*	*1.0*
9.3	10.0	10.7	11.4	12.1	12.8	13.5	1.1	Calf circ.	9.3	10.0	10.7	11.5	12.3	13.0	13.7	1.1
23.7	*25.5*	*27.2*	*29.0*	*30.8*	*32.5*	*34.3*	*2.7*		*23.5*	*25.4*	*27.2*	*29.2*	*31.2*	*33.0*	*34.9*	*2.6*

[1] … measurements made in the period 1956–1957 on 2150 boys and 2150 girls in Basle,

Normal Measurements During Growth – 13 Years to 14 Years[1]

Weight in pounds and *kilogrammes*, other measurements in inches and *centimetres* (P = percentile)

	Boys P10	Boys P25	Boys P50	Boys P75	Boys P90	Boys P97.5	Boys s		Girls P2.5	Girls P10	Girls P25	Girls P50	Girls P75	Girls P90	Girls P97.5	Girls s
								13 years								
	75.4	85.8	97.2	108.7	119.1	130.7	16.9	Weight								
	34.2	*38.9*	*44.1*	*49.3*	*54.0*	*59.3*	*7.67*									
	56.4	58.3	60.4	62.5	64.4	66.5	3.1	Height								
							7.8									
							1.7	Sitting height								
							4.3		*69.1*	*71.7*	*74.1*	*76.8*	*79.5*	*81.9*	*84.5*	*3.9*
							2.0	Shoulder width	11.2	11.9	12.5	13.2	13.9	14.5	15.2	1.0
							5.1		*28.5*	*30.3*	*31.8*	*33.6*	*35.4*	*36.9*	*38.7*	*2.6*
	8.4	9.3	10.4	11.4	12.3	13.1	1.5	Pelvic width	9.1	9.8	10.3	10.9	11.5	11.9	12.6	0.9
	21.4	*23.7*	*26.3*	*28.9*	*31.2*	*33.3*	*3.8*		*23.2*	*25.0*	*26.1*	*27.6*	*29.1*	*30.2*	*32.0*	*2.2*
	20.1	20.4	20.8	21.2	21.6	22.0	0.6	Head circ.	19.5	20.0	20.4	20.8	21.2	21.6	22.0	0.6
	51.0	*51.9*	*52.9*	*53.9*	*54.8*	*55.9*	*1.5*		*49.6*	*50.7*	*51.7*	*52.8*	*53.9*	*54.9*	*56.0*	*1.6*
	23.4	24.9	26.5	28.2	29.6	31.3	2.4	Chest circ.	20.6	22.4	23.9	25.7	27.4	29.0	30.7	2.6
	59.5	*63.2*	*67.4*	*71.6*	*75.3*	*79.5*	*6.1*		*52.3*	*56.8*	*60.8*	*65.2*	*69.6*	*73.6*	*78.1*	*6.5*
	6.7	7.5	8.3	9.2	10.0	10.9	1.3	Upper arm circ.	6.6	7.3	7.9	8.5	9.2	9.8	10.5	1.0
	16.9	*19.0*	*21.2*	*23.4*	*25.5*	*27.7*	*3.3*		*16.7*	*18.5*	*20.0*	*21.7*	*23.4*	*24.9*	*26.7*	*2.5*
	4.3	4.9	5.6	6.2	6.8	7.5	1.0	Wrist circ	–	–	–	5.6	–	–	–	0.4
	10.9	*12.4*	*14.1*	*15.8*	*17.3*	*19.1*	*2.5*		–	–	–	*14.2*	–	–	–	*0.9*
	9.8	10.6	11.6	12.5	13.3	14.3	1.4	Calf circ.	9.5	10.3	11.0	11.8	12.6	13.3	14.1	1.2
	24.9	*27.0*	*29.4*	*31.8*	*33.9*	*36.3*	*3.5*		*24.1*	*26.1*	*28.0*	*30.0*	*32.0*	*33.9*	*35.9*	*3.0*
								13½ years								
	79.8	90.4	102.1	113.8	124.3	136.2	17.2	Weight	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
	36.2	*41.0*	*46.3*	*51.6*	*56.4*	*61.8*	*7.81*									
	57.7	59.7	61.8	63.9	65.9	68.0	3.1	Height								
	146.6	*151.6*	*157.0*	*162.4*	*167.4*	*172.8*	*8.0*									
	28.4	29.5	30.6	31.8	32.8	34.0	1.7	Sitting height								
1	*72.2*	*74.9*	*77.8*	*80.7*	*83.4*	*86.3*	*4.3*		[illegible]	[illegible]	*75.4*	*77.9*	*80.4*	*82.6*	*85.0*	*3.6*
3	11.3	12.3	13.4	14.6	15.6	16.3	1.7	Shoulder width	11.5	12.2	12.8	13.5	14.1	14.7	15.4	1.0
5	*28.7*	*31.2*	*34.1*	*37.0*	*39.5*	*41.4*	*4.2*		*29.2*	*31.0*	*32.5*	*34.2*	*35.9*	*37.4*	*39.2*	*2.5*
9	8.9	9.7	10.6	11.6	12.4	13.3	1.4	Pelvic width	9.6	10.2	10.7	11.2	11.8	12.2	12.9	0.8
1	*22.5*	*24.6*	*27.0*	*29.4*	*31.5*	*33.9*	*3.5*		*24.3*	*26.0*	*27.1*	*28.5*	*29.9*	*31.0*	*32.7*	*2.1*
7	20.1	20.5	20.9	21.3	21.6	22.0	0.6	Head circ.	19.7	20.1	20.5	20.9	21.3	21.6	22.0	0.6
0	*51.1*	*52.0*	*53.0*	*54.0*	*54.9*	*56.0*	*1.5*		*50.0*	*51.1*	*52.0*	*53.0*	*54.0*	*54.9*	*56.0*	*1.5*
3	23.4	25.2	27.2	29.3	31.1	33.1	3.0	Chest circ	21.0	22.8	24.3	26.1	27.8	29.4	31.1	2.6
2	*59.4*	*64.0*	*69.2*	*74.4*	*79.0*	*84.2*	*7.6*		*53.3*	*57.8*	*61.8*	*66.2*	*70.6*	*74.6*	*79.1*	*6.5*
3	7.0	7.7	8.5	9.2	9.9	10.6	1.1	Upper arm circ	6.8	7.4	8.0	8.7	9.3	9.9	10.6	0.9
0	*17.9*	*19.6*	*21.5*	*23.4*	*25.1*	*27.0*	*2.8*		*17.2*	*18.9*	*20.4*	*22.0*	*23.6*	*25.1*	*26.8*	*2.4*
9	4.5	5.1	5.7	6.3	6.9	7.5	0.9	Wrist circ	–	–	–	5.6	–	–	–	0.4
9	*11.5*	*12.9*	*14.5*	*16.1*	*17.5*	*19.1*	*2.3*		–	–	–	*14.3*	–	–	–	*0.9*
9	9.9	10.8	11.8	12.8	13.7	14.7	1.5	Calf circ	9.8	10.6	11.3	12.2	13.0	13.7	14.6	1.2
7	*25.2*	*27.5*	*30.0*	*32.5*	*34.8*	*37.3*	*3.7*		*24.8*	*26.9*	*28.8*	*30.9*	*33.0*	*34.9*	*37.0*	*3.1*
								14 years								
5	84.4	95.2	107.1	119.0	129.9	141.8	17.5	Weight	74.3	86.9	97.9	110.5	123.0	134.0	146.6	18.3
9	*33.3*	*43.2*	*48.6*	*54.0*	*58.9*	*64.3*	*7.92*		*33.7*	*39.4*	*44.4*	*50.1*	*55.8*	*60.8*	*66.5*	*8.3*
0	59.1	61.1	63.2	65.4	67.3	69.4	3.1	Height	57.8	59.4	60.7	62.3	63.8	65.2	66.7	2.2
3	*150.2*	*155.2*	*160.6*	*166.0*	*171.0*	*176.4*	*8.0*		*146.9*	*150.8*	*154.3*	*158.2*	*162.1*	*165.6*	*169.5*	*5.7*
8	29.0	30.0	31.2	32.4	33.5	34.6	1.7	Sitting height	28.5	29.4	30.2	31.1	32.0	32.8	33.7	1.3
6	*73.6*	*76.3*	*79.3*	*82.3*	*85.0*	*88.0*	*4.4*		*72.3*	*74.6*	*76.7*	*79.0*	*81.3*	*83.4*	*85.7*	*3.4*
13	12.6	13.2	13.9	14.6	15.3	15.5	1.1	Shoulder width	11.9	12.5	13.1	13.7	14.4	15.0	15.6	0.9
5	*31.9*	*33.6*	*35.4*	*37.2*	*38.9*	*39.4*	*2.7*		*30.1*	*31.8*	*33.3*	*34.9*	*36.5*	*38.0*	*39.7*	*2.4*
1	9.8	10.4	11.0	11.7	12.3	13.0	1.0	Pelvic width	10.0	10.5	11.0	11.5	12.1	12.6	13.1	0.8
0	*24.8*	*26.3*	*28.0*	*29.7*	*31.2*	*33.0*	*2.5*		*25.3*	*26.7*	*27.9*	*29.3*	*30.7*	*31.9*	*33.3*	*2.0*
97	20.2	20.5	20.9	21.3	21.7	22.1	0.6	Head circ	19.8	20.2	20.6	20.9	21.3	21.7	22.1	0.6
0	*51.2*	*52.1*	*53.1*	*54.1*	*55.0*	*56.1*	*1.5*		*50.2*	*51.3*	*52.2*	*53.2*	*54.2*	*55.1*	*56.2*	*1.5*
28	24.6	26.1	27.9	29.7	31.3	33.1	2.6	Chest circ	21.4	23.1	24.6	26.4	28.1	29.6	31.4	2.5
5	*62.4*	*65.4*	*70.9*	*75.4*	*79.4*	*84.0*	*6.6*		*54.3*	*58.7*	*62.6*	*67.0*	*71.4*	*75.3*	*79.7*	*6.4*
72	7.7	8.1	8.7	9.2	9.6	10.2	0.7	Upper arm circ	7.0	7.6	8.1	8.8	9.4	10.0	10.6	0.9
2	*19.5*	*20.7*	*22.0*	*23.3*	*24.5*	*25.8*	*1.9*		*17.7*	*19.3*	*20.7*	*22.3*	*23.9*	*25.3*	*26.9*	*2.3*
4.3	4.9	5.4	5.9	6.5	6.9	7.5	0.8	Wrist circ	–	–	–	5.7	–	–	–	0.4
10.0	*12.4*	*13.6*	*15.0*	*15.4*	*17.6*	*19.0*	*2.0*		–	–	–	*14.4*	–	–	–	*0.9*
10.0	10.7	11.4	12.1	12.8	13.5	14.2	1.1	Calf circ	10.2	10.9	11.7	12.5	13.3	14.0	14.8	1.2
[illegible]	*27.3*	*29.0*	*30.5*	*32.6*	*34.3*	*35.1*	*2.7*		*25.8*	*27.8*	*29.7*	*31.7*	*33.7*	*35.6*	*37.6*	*3.0*

[1] Heimendinger, J. *Helv paediat. Acta* 19 suppl 13 (1964). From measurements made in the period 1956–1957 on 2150 boys and 2150 girls in [illegible]

Normal Measurements During Growth – 14½ Years to 15½ Years[1]

Weight in pounds and *kilogrammes*; other measurements in inches and *centimetres* (P = percentile)

Boys									Girls							
	95%									95%						
	80%									80%						
		50%									50%					
$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s		$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	
								14½ years								
75.6	88.4	99.6	112.2	124.8	136.0	148.8	18.5	Weight	81.3	92.8	103.0	114.2	125.4	135.6	147.0	16
34.3	*40.1*	*45.2*	*50.9*	*56.6*	*61.7*	*67.5*	*8.37*		*36.9*	*42.1*	*46.7*	*51.8*	*56.9*	*61.5*	*66.7*	*7*
58.3	60.5	62.4	64.5	66.6	68.5	70.6	3.1	Height	58.9	60.0	61.4	62.9	64.4	65.8	66.9	2
148.2	*153.6*	*158.4*	*163.8*	*169.2*	*174.0*	*179.4*	*7.9*		*149.7*	*152.5*	*156.0*	*159.8*	*163.6*	*167.1*	*169.9*	*5*
28.4	29.6	30.6	31.8	33.0	34.1	35.2	1.7	Sitting height	29.0	29.8	30.7	31.5	32.4	33.2	34.1	1
72.1	*75.1*	*77.8*	*80.8*	*83.8*	*86.5*	*89.5*	*4.4*		*73.6*	*75.8*	*77.9*	*80.1*	*82.3*	*84.4*	*86.6*	*3*
12.5	13.1	13.7	14.4	15.0	15.6	16.3	0.9	Shoulder width	12.2	12.8	13.4	14.0	14.6	15.2	15.8	0
31.7	*33.4*	*34.9*	*36.5*	*38.1*	*39.6*	*41.3*	*2.4*		*31.0*	*32.6*	*34.0*	*35.6*	*37.2*	*38.6*	*40.2*	*2*
9.8	10.4	10.9	11.4	12.0	12.5	13.1	0.8	Pelvic width	10.3	10.8	11.3	11.8	12.3	12.8	13.3	0
24.8	*26.3*	*27.6*	*29.0*	*30.4*	*31.7*	*33.2*	*2.1*		*26.1*	*27.4*	*28.6*	*29.9*	*31.2*	*32.4*	*33.7*	*1.*
19.8	20.2	20.6	21.0	21.4	21.7	22.2	0.6	Head circ.	19.8	20.2	20.6	21.0	21.5	21.9	22.3	0.
50.3	*51.4*	*52.3*	*53.3*	*54.3*	*55.2*	*56.3*	*1.5*		*50.2*	*51.3*	*52.3*	*53.4*	*54.5*	*55.5*	*56.6*	*1.*
24.2	25.7	27.0	28.5	30.0	31.3	32.8	2.2	Chest circ.	21.7	23.4	25.0	26.7	28.3	29.9	31.6	2.
61.5	*65.3*	*68.7*	*72.4*	*76.1*	*79.5*	*83.3*	*5.5*		*55.2*	*59.5*	*63.4*	*67.7*	*72.0*	*75.9*	*80.2*	*6.*
7.4	8.0	8.4	8.9	9.4	9.9	10.4	0.7	Upper arm circ.	7.2	7.8	8.3	8.9	9.4	10.0	10.6	0.
18.9	*20.2*	*21.4*	*22.7*	*24.0*	*25.2*	*26.5*	*1.9*		*18.4*	*19.9*	*21.2*	*22.6*	*24.0*	*25.3*	*26.8*	*2.*
4.8	5.2	5.6	6.0	6.5	6.9	7.3	0.6	Wrist circ.	–	–	–	5.7	–	–	–	0.
12.1	*13.2*	*14.2*	*15.3*	*16.4*	*17.4*	*18.5*	*1.6*		–	–	–	*14.5*	–	–	–	*0.*
10.6	11.3	11.9	12.6	13.3	13.9	14.6	1.0	Calf circ.	10.4	11.1	11.9	12.6	13.4	14.1	14.9	1.
27.0	*28.8*	*30.3*	*32.0*	*33.7*	*35.2*	*37.0*	*2.5*		*26.4*	*28.3*	*30.1*	*32.1*	*34.1*	*35.9*	*37.8*	*2.*
								15 years								
81.1	93.7	104.7	117.1	129.4	140.4	153.0	18.1	Weight	87.1	97.7	106.9	117.3	127.6	136.9	147.5	15.
36.8	*42.5*	*47.5*	*53.1*	*58.7*	*63.7*	*69.4*	*8.22*		*39.5*	*44.3*	*48.5*	*53.2*	*57.9*	*62.1*	*66.9*	*6.*
59.8	61.9	63.7	65.7	67.7	69.5	71.5	3.0	Height	59.4	60.6	61.9	63.4	64.9	66.3	67.4	2.
151.9	*157.1*	*161.7*	*166.8*	*171.9*	*176.5*	*181.7*	*7.5*		*151.0*	*153.8*	*157.3*	*161.1*	*164.9*	*168.4*	*171.2*	*5.*
28.9	30.1	31.1	32.4	33.6	34.6	35.9	1.8	Sitting height	29.5	30.4	31.1	32.0	32.8	33.6	34.4	1.
73.3	*76.4*	*79.1*	*82.2*	*85.3*	*88.0*	*91.1*	*4.5*		*74.9*	*77.1*	*79.0*	*81.2*	*83.4*	*85.3*	*87.5*	*3.*
13.0	13.6	14.1	14.7	15.3	15.8	16.5	0.9	Shoulder width	12.4	13.1	13.6	14.2	14.8	15.3	15.9	0.
33.0	*34.6*	*35.9*	*37.4*	*38.9*	*40.2*	*41.8*	*2.2*		*31.6*	*33.2*	*34.5*	*36.0*	*37.5*	*38.8*	*40.4*	*2.*
10.0	10.6	11.1	11.7	12.2	12.8	13.3	0.8	Pelvic width	10.5	10.9	11.4	11.9	12.4	12.9	13.3	0.
25.5	*27.0*	*28.3*	*29.7*	*31.1*	*32.4*	*33.9*	*2.1*		*26.6*	*27.7*	*28.9*	*30.2*	*31.5*	*32.7*	*33.8*	*1.*
19.8	20.3	20.6	21.0	21.4	21.8	22.2	0.6	Head circ.	19.9	20.3	20.7	21.1	21.5	21.8	22.2	0.
50.4	*51.5*	*52.4*	*53.4*	*54.4*	*55.3*	*56.4*	*1.5*		*50.5*	*51.6*	*52.5*	*53.5*	*54.5*	*55.4*	*56.5*	*1.*
25.2	26.5	27.8	29.1	30.4	31.7	33.0	2.0	Chest circ.	22.1	23.8	25.2	26.9	28.5	30.0	31.7	2.
64.0	*67.4*	*70.5*	*73.9*	*77.3*	*80.4*	*83.8*	*5.0*		*56.2*	*60.4*	*64.1*	*68.3*	*72.5*	*76.2*	*80.4*	*6.*
7.6	8.1	8.6	9.2	9.7	10.2	10.7	0.8	Upper arm circ.	7.4	8.0	8.5	9.0	9.6	10.0	10.6	0.
19.3	*20.7*	*21.9*	*23.3*	*24.7*	*25.9*	*27.3*	*2.0*		*18.9*	*20.3*	*21.5*	*22.9*	*24.3*	*25.5*	*26.9*	*2.*
5.1	5.4	5.7	6.1	6.5	6.8	7.1	0.5	Wrist circ.	–	–	–	5.7	–	–	–	0.
12.9	*13.8*	*14.6*	*15.5*	*16.4*	*17.2*	*18.1*	*1.3*		–	–	–	*14.5*	–	–	–	*0.*
11.0	11.7	12.2	12.9	13.5	14.1	14.8	0.9	Calf circ.	10.7	11.4	12.0	12.7	13.4	14.1	14.7	1.
27.9	*29.6*	*31.1*	*32.7*	*34.3*	*35.8*	*37.5*	*2.4*		*27.2*	*28.9*	*30.5*	*32.3*	*34.1*	*35.7*	*37.4*	*2.*
								15½ years								
86.9	99.0	110.0	122.1	134.3	145.3	157.4	17.8	Weight	90.4	100.5	109.6	119.7	129.9	138.9	149.0	14.8
39.4	*44.9*	*49.9*	*55.4*	*60.9*	*65.9*	*71.4*	*8.09*		*41.0*	*45.6*	*49.7*	*54.3*	*58.9*	*63.0*	*67.6*	*6.7*
61.3	63.2	64.9	66.7	68.6	70.2	72.1	2.7	Height	59.3	60.9	62.2	63.8	65.4	66.8	68.3	2.3
155.8	*160.6*	*164.8*	*169.5*	*174.2*	*178.4*	*183.2*	*6.9*		*150.6*	*154.6*	*158.1*	*162.1*	*166.1*	*169.6*	*173.6*	*5.8*
29.5	30.7	31.8	33.0	34.1	35.2	36.4	1.7	Sitting height	29.9	30.8	31.5	32.4	33.3	34.0	34.9	1.3
75.0	*78.0*	*80.7*	*83.7*	*86.7*	*89.4*	*92.4*	*4.4*		*76.0*	*78.2*	*80.1*	*82.3*	*84.5*	*86.4*	*88.6*	*3.2*
13.1	14.0	14.5	15.0	15.6	16.1	16.4	0.8	Shoulder width	12.6	13.2	13.7	14.3	14.8	15.3	15.9	0.8
33.2	*35.5*	*36.8*	*38.2*	*39.6*	*40.9*	*41.6*	*2.1*		*32.0*	*33.5*	*34.8*	*36.2*	*37.6*	*38.9*	*40.4*	*2.1*
10.3	10.9	11.4	11.9	12.5	13.0	13.6	0.8	*Pelvic width*	10.6	11.1	11.5	12.0	12.5	12.9	13.4	0.7
26.1	*27.6*	*28.9*	*30.3*	*31.7*	*33.0*	*34.5*	*2.1*		*26.9*	*28.2*	*29.3*	*30.5*	*31.7*	*32.8*	*34.1*	*1.8*
20.0	20.4	20.7	21.1	21.5	21.8	22.2	0.6	Head circ.	20.0	20.4	20.7	21.1	21.5	21.9	22.2	0.6
50.7	*51.7*	*52.5*	*53.5*	*54.5*	*55.3*	*56.3*	*1.4*		*50.9*	*51.9*	*52.7*	*53.7*	*54.7*	*55.5*	*56.5*	*1.4*
25.9	27.2	28.3	29.6	30.9	32.0	33.3	1.9	Chest circ.	22.6	24.1	25.5	27.1	28.7	30.0	31.6	2.3
65.9	*69.1*	*72.0*	*75.2*	*78.4*	*81.3*	*84.5*	*4.7*		*57.3*	*61.3*	*64.8*	*68.8*	*72.8*	*76.3*	*80.3*	*5.8*
7.6	8.2	8.7	9.3	9.9	10.4	11.0	0.9	Upper arm circ.	7.8	8.3	8.7	9.2	9.6	10.1	10.6	0.7
19.2	*20.8*	*22.1*	*23.6*	*25.1*	*26.4*	*28.0*	*2.2*		*19.7*	*21.0*	*22.1*	*23.3*	*24.5*	*25.6*	*26.9*	*1.8*
5.3	5.6	5.9	6.1	6.4	6.7	7.0	0.4	Wrist circ.	–	–	–	5.7	–	–	–	0.4
13.4	*14.2*	*14.9*	*15.6*	*16.3*	*17.0*	*17.8*	*1.1*		–	–	–	*14.5*	–	–	–	*0.9*
11.2	11.9	12.4	13.0	13.7	14.2	14.8	0.9	Calf circ.	10.9	11.6	12.2	12.8	13.4	14.0	14.7	0.9
28.5	*30.1*	*31.5*	*33.1*	*34.7*	*36.1*	*37.7*	*2.3*		*27.7*	*29.4*	*30.9*	*32.5*	*34.1*	*35.6*	*37.3*	*2.4*

[1] HEIMENDINGER, J., *Helv. paediat. Acta*, 19, suppl. 13 (1964). From measurements made in the period 1956–1957 on 2150 boys and 2150 girls in Basle.

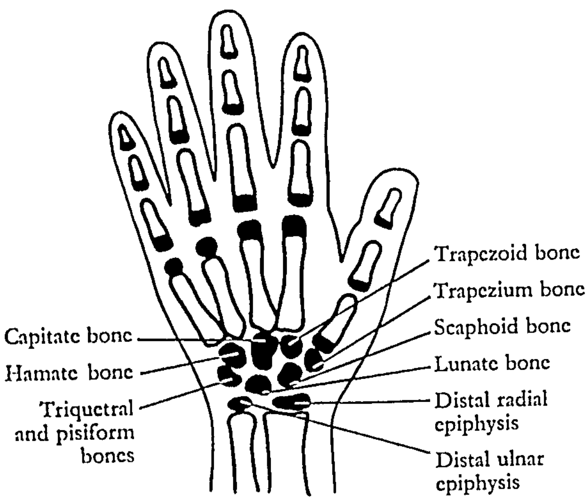
Normal Measurements During Growth – 16 Years to 17 Years[1]

Weight in pounds and *kilogrammes*, other measurements in inches and *centimetres* (P = percentile)

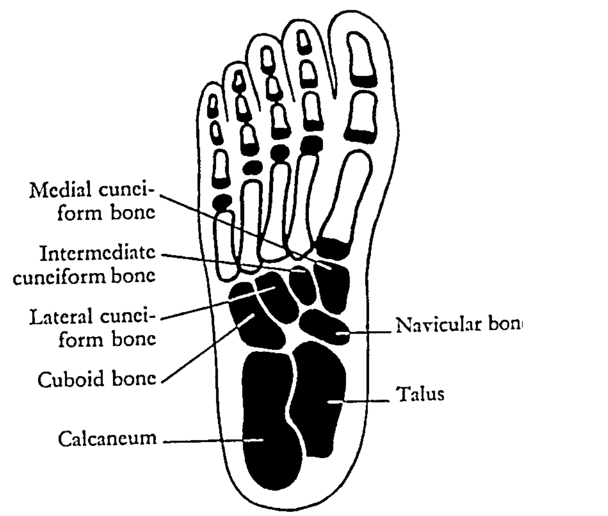
Boys									Girls							
	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s		$P_{2.5}$	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	$P_{97.5}$	s
								16 years								
								Weight								
							8									
								Height								
								Sitting height								
							3	Shoulder width								
							7									
							7	Pelvic width								
							9									
							5	Head circ.	20.1	20.5	20.8	21.1	21.5	21.8	22.2	0.6
							4		*51.1*	*52.0*	*52.8*	*53.7*	*54.6*	*55.4*	*56.3*	*1.4*
							7	Chest circ.	23.0	24.4	25.8	27.2	28.7	30.0	31.5	2.2
							4		*58.3*	*62.1*	*65.5*	*69.2*	*72.9*	*76.3*	*80.1*	*5.5*
							9	Upper arm circ	7.9	8.4	8.8	9.3	9.8	10.2	10.7	0.7
							3		*20.0*	*21.3*	*22.4*	*23.6*	*24.8*	*25.9*	*27.2*	*1.8*
							4	Wrist circ	–	–	–	5.7	–	–	–	0.3
							0		–	–	–	*14.5*	–	–	–	*0.7*
							9	Calf circ	11.0	11.7	12.2	12.8	13.5	14.0	14.6	0.9
							2		*28.0*	*29.6*	*31.0*	*32.6*	*34.2*	*35.6*	*37.2*	*2.3*
								16½ years								
9	110.9	121.0	132.1	143.1	153.2	164.2	16.3	Weight	93.5	103.8	113.1	123.2	133.4	142.6	153.0	15.0
1	*50.3*	*54.9*	*59.9*	*64.9*	*69.5*	*74.5*	*7.38*		*42.4*	*47.1*	*51.3*	*55.9*	*60.5*	*64.7*	*69.4*	*6.8*
5	65.2	66.6	68.3	69.9	71.4	73.0	2.4	Height	59.7	61.3	62.8	64.4	66.0	67.4	69.1	2.4
3	*165.5*	*169.2*	*173.4*	*177.6*	*181.3*	*185.5*	*6.1*									*6.0*
4	32.2	33.0	34.0	34.9	35.7	36.8	1.4	Sitting height								1.3
97	*81.8*	*83.9*	*86.3*	*88.7*	*90.8*	*93.5*	*3.5*									*3.2*
40	14.5	15.0	15.6	16.1	16.6	17.1	0.8	Shoulder width								0.7
55	*36.9*	*38.1*	*39.5*	*40.9*	*42.1*	*43.5*	*2.0*									*1.9*
10	11.5	11.9	12.3	12.8	13.2	13.7	0.7	Pelvic width								0.7
79	*29.1*	*30.1*	*31.3*	*32.5*	*33.5*	*34.7*	*1.7*									*1.8*
00	20.4	20.7	21.1	21.5	21.9	22.2	0.6	Head circ								0.6
09	*51.9*	*52.7*	*53.7*	*54.7*	*55.5*	*56.5*	*1.4*									*1.4*
72	28.3	29.3	30.5	31.6	32.6	33.7	1.7	Chest circ								2.0
91	*72.0*	*74.5*	*77.4*	*80.3*	*82.8*	*85.7*	*4.2*									*5.2*
78	8.4	8.9	9.5	10.1	10.6	11.2	0.9	Upper arm circ	8.0	8.5	8.9	9.4	9.9	10.3	10.8	0.7
97	*21.3*	*22.6*	*24.1*	*25.6*	*26.9*	*28.5*	*2.2*		*20.3*	*21.6*	*22.7*	*23.9*	*25.1*	*26.2*	*27.5*	*1.8*
54	5.7	5.9	6.2	6.5	6.7	7.0	0.4	Wrist circ	–	–	–	5.7	–	–	–	0.3
18	*14.5*	*15.1*	*15.8*	*16.5*	*17.1*	*17.8*	*1.0*		–	–	–	*14.5*	–	–	–	*0.7*
11.4	12.0	12.6	13.1	13.7	14.3	14.9	0.9	Calf circ	11.1	11.7	12.2	12.9	13.5	14.1	14.7	0.9
29.0	*30.6*	*31.9*	*33.4*	*34.9*	*36.2*	*37.8*	*2.2*		*28.1*	*29.7*	*31.1*	*32.7*	*34.3*	*35.7*	*37.3*	*2.3*
								17 years								
04.9	114.9	123.9	134.0	144.2	153.2	163.1	14.7	Weight	94.8	105.2	114.4	124.6	134.7	144.0	154.3	15.0
47.6	*52.1*	*56.2*	*60.8*	*65.4*	*69.5*	*74.0*	*6.69*		*43.0*	*47.7*	*51.9*	*56.5*	*61.1*	*65.3*	*70.0*	*6.8*
64.0	65.6	67.0	68.6	70.2	71.6	73.2	2.3	Height	59.7	61.3	62.8	64.5	66.1	67.6	69.3	2.4
62.6	*166.7*	*170.3*	*174.3*	*178.3*	*181.9*	*186.0*	*5.9*		*151.7*	*155.8*	*159.6*	*163.8*	*168.0*	*171.8*	*175.9*	*6.1*
31.5	32.4	33.2	34.1	35.0	35.8	36.7	1.3	Sitting height	30.4	31.3	32.0	32.9	33.7	34.5	35.4	1.3
79.9	*82.2*	*84.3*	*86.6*	*88.9*	*91.0*	*93.3*	*3.4*		*77.2*	*79.4*	*81.3*	*83.5*	*85.7*	*87.6*	*89.8*	*3.2*
14.3	14.8	15.2	15.7	16.3	16.7	17.2	0.7	Shoulder width	12.9	13.4	13.9	14.4	14.9	15.4	15.9	0.7
35.2	*37.5*	*38.7*	*40.0*	*41.3*	*42.5*	*43.8*	*1.9*		*32.7*	*34.0*	*35.2*	*36.5*	*37.8*	*39.0*	*40.3*	*1.9*
11.3	11.7	12.0	12.4	12.8	13.2	13.6	0.6	Pelvic width	11.0	11.5	11.9	12.4	12.9	13.3	13.8	0.7
28.6	*29.7*	*30.6*	*31.6*	*32.6*	*33.5*	*34.6*	*1.5*		*27.9*	*29.2*	*30.3*	*31.5*	*32.7*	*33.8*	*35.1*	*1.8*
20.0	20.4	20.8	21.2	21.6	21.9	22.4	0.6	Head circ	20.1	20.5	20.8	21.1	21.5	21.8	22.2	0.6
50.9	*51.9*	*52.8*	*53.8*	*54.8*	*55.7*	*56.8*	*1.5*		*51.1*	*52.0*	*52.8*	*53.7*	*54.6*	*55.4*	*56.3*	*1.4*
27.6	28.7	29.7	30.9	32.0	33.0	34.1	1.7	Chest circ	23.5	24.9	26.1	27.4	28.7	29.8	31.2	1.9
70.1	*73.0*	*75.5*	*78.4*	*81.3*	*83.8*	*86.7*	*4.2*		*59.8*	*63.2*	*66.2*	*69.5*	*72.8*	*75.8*	*79.2*	*4.9*
7.9	8.5	9.0	9.5	10.1	10.6	11.2	0.8	Upper arm circ	8.1	8.6	9.1	9.5	10.0	10.4	10.9	0.7
20.0	*21.5*	*22.9*	*24.2*	*25.6*	*26.9*	*28.4*	*2.1*		*20.6*	*21.9*	*23.0*	*24.2*	*25.4*	*26.5*	*27.8*	*1.8*
5.5	5.7	6.0	6.2	6.5	6.7	6.9	0.4	Wrist circ	–	–	–	5.7	–	–	–	0.3
14.0	*14.6*	*15.2*	*15.8*	*16.4*	*17.0*	*17.6*	*0.9*		–	–	–	*14.5*	–	–	–	*0.7*
11.5	12.1	12.6	13.2	13.7	14.3	14.8	0.8	Calf circ	11.1	11.7	12.3	12.9	13.5	14.1	14.7	0.9
29.1	*30.9*	*32.1*	*33.5*	*34.9*	*36.2*	*37.7*	*2.1*		*28.2*	*29.8*	*31.2*	*32.8*	*34.4*	*35.8*	*37.4*	*2.3*

[1] Heimendinger J, *Helv paediat Acta* 19 suppl 13 (1964). From measurements made in the period 1956–1957 on 2150 boys and 2150 girls in Basle, Switzerland

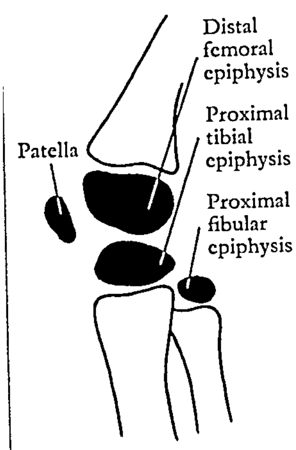
HAND AND WRIST



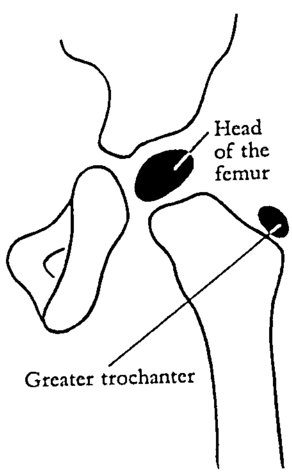
FOOT



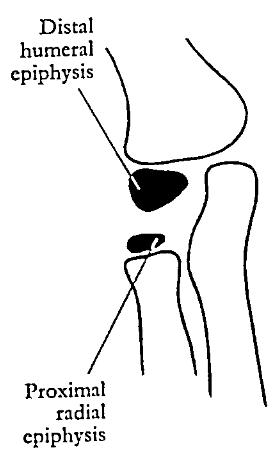
KNEE



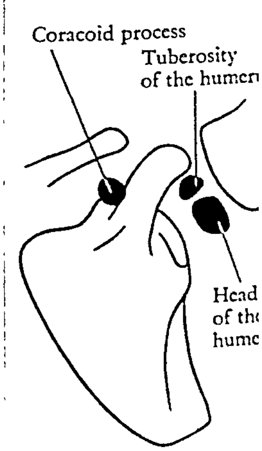
HIP



ELBOW



SHOULDER



In many clinical situations the assessment of skeletal development is a matter of considerable importance. Various regional ossification processes occurring between birth and maturity can be utilized for this purpose.

For routine clinical purposes the following indications constitute a reliable guide to skeletal development.

Newborn

In the full-term infant, knee X-rays (anteroposterior or lateral) should reveal a distinct and well-formed distal femoral epiphysis.

Bone age in childhood[1-6]

The extent to which regional epiphyses are early or late in appearing can be determined by means of the table on page 707. In doing so it must be borne in mind that the range of physiol variation is rather wide, and that a discordance in the ti appearance of various ossification centres is commonly met For this reason, diagnostic X-rays should include several re of the body (wrist, knee and foot, possibly others).

Bone age in the hand can be readily assessed by means table on page 708. For other bones and for a more detailed ation of bone age see the special atlases[1-4].

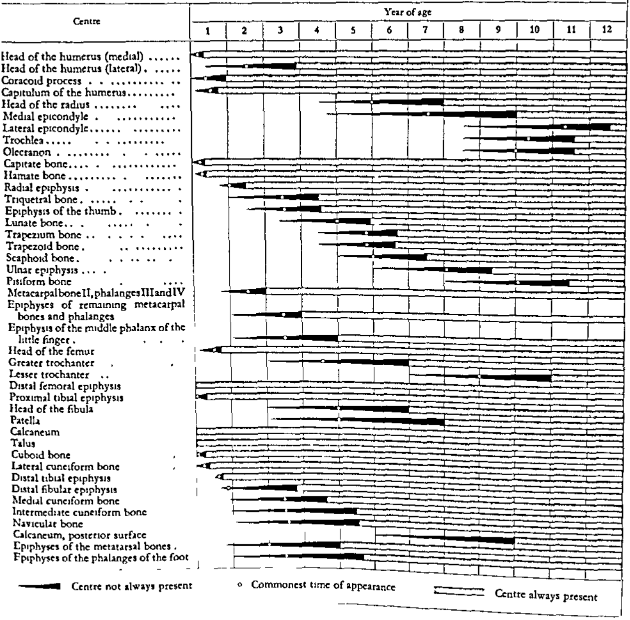
In assessing bone development at and during puberty it m remembered that girls have a bone age about two years in ad of that of boys of the same age.

Bone development and the onset of puberty

The onset of puberty can be predicted far more reliably fro state of bone development than from height, while chronol age is an even more unreliable guide. When bone developm

* The data on pages 706–708 have been compiled in collaboration with H. J. KAUFMANN, Children's Hospital, Basle.

Time of appearance of the ossification centres of the limb bones[7]



rapid and uninterrupted the onset of puberty will be early, and vice versa. In a similar way the time of appearance and state of development of the various ossification centres are directly related to the individual's eventual height. Thus from the age of 6 years

six months of the commencement of ossification of the apophysis of the iliac crest

Conditions in which it is important to determine bone age

Hypothyroidism This is marked by a distinct delay in the appearance of the ossification centres. Serial determinations of bone age should accompany treatment. Excessively rapid skeletal development involves the danger of dwarfism.

Pituitary dwarfism Bone age and longitudinal growth are delayed to the same extent.

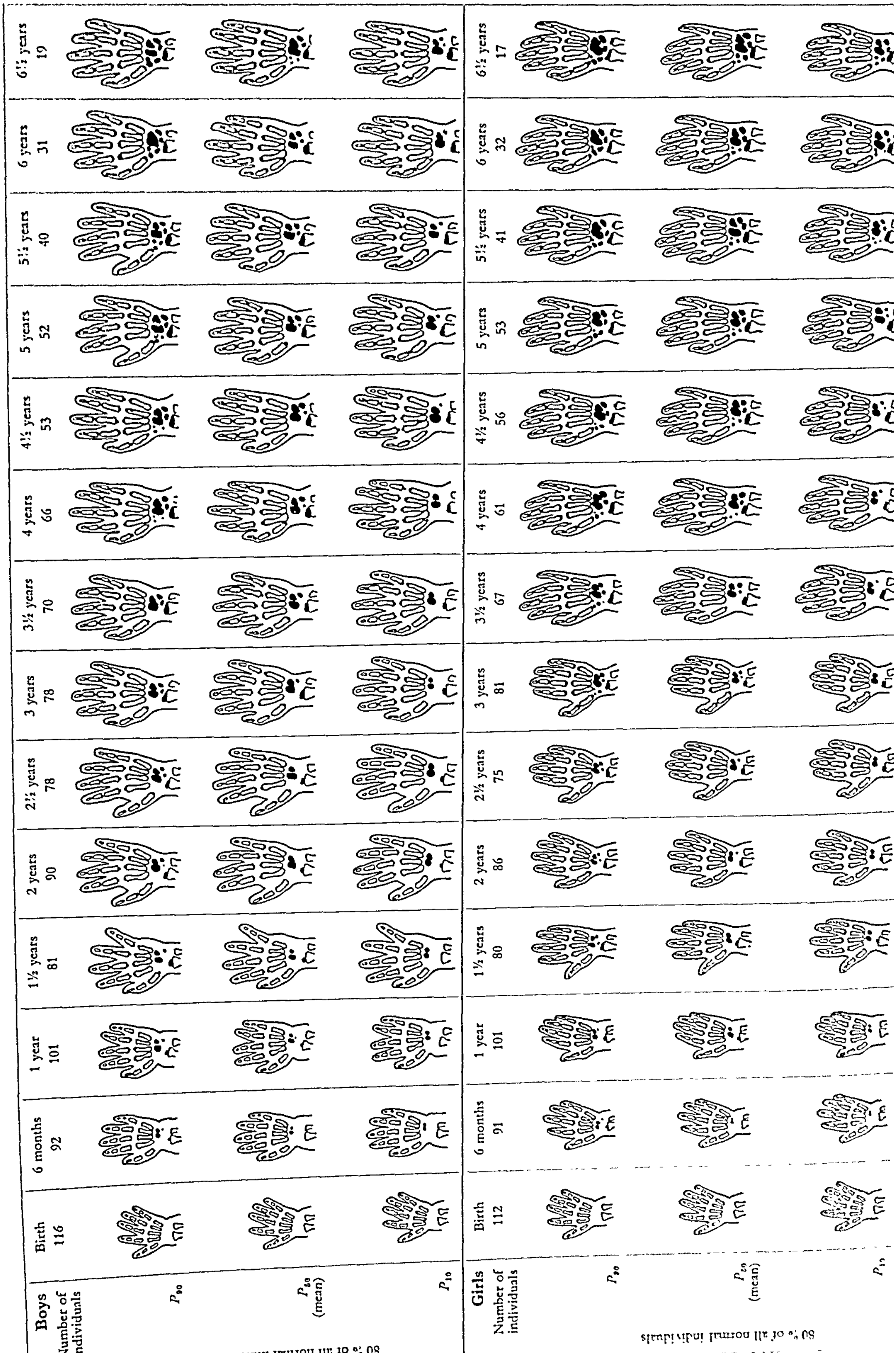
Primordial dwarfism Longitudinal growth is delayed but ossification remains practically normal for the child's age.

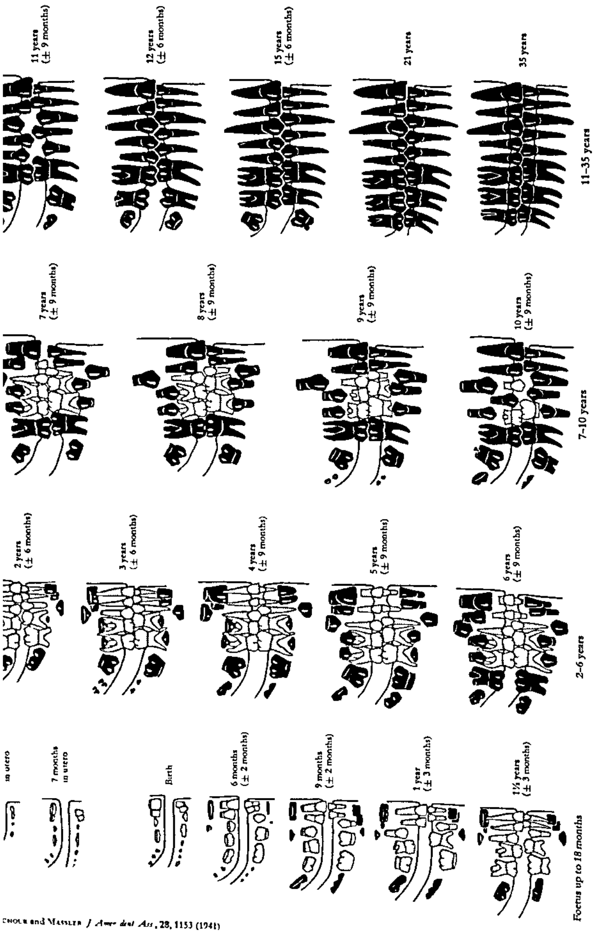
Pituitary gigantism Again due to discordance, longitudinal growth being very advanced while ossification is normal for the child's age.

Adrenogenital syndrome ... is far ... union

Pitu... both bone development and longitudinal growth are abnormally rapid, the former more so than the latter.

References


Boys
Number of individuals
Birth 116
6 months 92
1 year 101
1½ years 81
2 years 90
2½ years 78
3 years 78
3½ years 70
4 years 66
4½ years 53
5 years 52
5½ years 40
6 years 31
6½ years 19
P_{90}
P_{50} (mean)
P_{10}
80 % of all normal individuals
Girls
Number of individuals
Birth 112
6 months 91
1 year 101
1½ years 80
2 years 86
2½ years 75
3 years 81
3½ years 67
4 years 61
4½ years 56
5 years 53
5½ years 41
6 years 32
6½ years 17
P_{90}
P_{50} (mean)
P_{10}
80 % of all normal individuals



chour and Massler *J. Amer. dent. Ass.*, 28, 1153 (1941)

Organ weights at various ages (in grammes)[1]

	Lungs		Brain		Heart		Kidneys		Liver		Spleen	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Wo[men]
Newborn	51.7	50.9	353	347	19	20	24	24	124	125	8	
0–3 months	68.8	63.6	435	411	–	–	–	–	–	–	–	–
3–6 months	94.1	93.3	600	534	–	–	–	–	–	–	–	–
6–9 months	128.5	114.7										
9–12 months	142.4	142.1	877	726	41	36	60	52	300	240	26	2
1–2 years	170.3	175.3	971	894	54	48	72	65	400	390	35	3
2–3 years	245.9	244.3	1076	1012	63	62	85	75	460	450	42	4
3–4 years	304.7	265.5	1179	1076	73	71	93	84	510	500	48	4
4–5 years	314.2	311.7	1290	1156	83	80	100	93	555	550	53	5
5–6 years	260.6	319.9	1275	1206	95	90	106	102	595	590	58	5
6–7 years	399.5	357.5	1313	1225	103	100	112	112	630	635	62	6
7–8 years	365.4	404.4	1338	1265	110	113	120	123	665	685	64	6
8–9 years	405.0	382.1	1294	1208	122	126	128	135	715	745	68	71
9–10 years	376.4	358.4	1360	1226	132	140	138	148	770	810	73	77
10–11 years	474.5	571.2	1378	1247	144	154	150	163	850	880	82	85
11–12 years	465.6	535.0	1348	1259	157	168	164	180	950	960	91	93
12–13 years	458.8	681.7	1383	1256	180	188	178	195	1050	1080	101	103
13–14 years	504.5	602.3	1382	1243	202	207	196	210	1150	1180	111	112
14–15 years	692.8	517.0	1356	1318	238	226	212	222	1240	1270	121	120
15–16 years	691.7	708.8	1407	1271	258	238	229	230	1315	1330	135	127
16–17 years	747.3	626.5	1419	1300	282	243	244	236	1380	1360	145	134
17–18 years	776.9	694.5	1409	1254	300	247	260	240	1450	1380	152	140
18–19 years	874.7	654.9	1426	1312	310	250	270	244	1510	1395	157	146
19–20 years	1035.6	785.2	1430	1294	318	251	282	247	1580	1405	160	151
20–21 years	*953.0*	*792.8*	–	–	*322*	*252*	*290*	*248*	*1630*	*1415*	*162*	*155*

Weights of endocrine organs (in grammes) (values are for both sexes)[1]

	Adrenals	Pituitary	Thymus	Pancreas	Thyroid
Newborn	9.04	–	10.9	2.77	2.09
2–14 days	5.19	–	–	–	–
0–1 month	–	–	–	2.42	–
1–2 months	–	–	–	2.63	–
0–3 months	–	–	–	–	1.71
2–3 *months*	–	–	–	4.46	–
0–6 months	–	0.113	–	–	–
3–6 months	3.91	–	–	5.38	2.11
1 day to 12 months	–	–	19.5	–	–
6–12 months	4.73	0.127	–	9.24	2.04
1–2 years	3.56	0.148	–	13.54	2.53
1–3 years	–	–	23.0	–	–
2–3 years	–	–	–	–	3.40

	Adrenals	Pituitary	Thymus	Pancreas	Thyroid
2–4 years	–	–	–	19.44	–
2–5 years	4.71	0.194	–	–	–
3–5 years	–	–	28.0	–	–
4–6 years	–	–	–	22.44	5.24
6–8 years	–	–	–	28.46	7.05
5–10 years	5.19	0.257	28.5	–	–
8–10 years	–	–	–	26.53	9.30
10–12 years	–	–	–	29.25	8.69
12–14 years	–	–	–	–	14.82
10–15 years	7.00	0.380	29.5	–	–
14–16 years	–	–	–	–	14.48
16–18 years	–	–	–	–	16.62
15–20 years	10.00	0.556	21.0	68.33	–
18–20 years	–	–	–	–	18.33
20–25 years	–	–	18.6	–	–

Weights of reproductive organs (in grammes)[1]

	Testes	Testes and epididymides	*Seminal vesicles*	Prostate	Ovaries	*Uterine tubes*	Uterus
Newborn	0.85	0.91	0.050	0.82	0.33	0.29	3.90
0–1 year	1.03	1.33	0.052	0.9	0.62	0.26	1.42
1–2 years	–	–	–	–	0.84	0.29	1.50
1–3 years	1.48	1.82	–	1.2	–	–	–
2–4 years	–	–	–	–	1.12	–	2.30
3–5 years	1.64	1.76	–	1.1	–	–	–
4–7 years	–	–	–	–	1.90	–	2.80
5–10 years	1.67	2.24	0.099	1.3	–	–	–
10–12 years	2.00	4.00	0.120	1.9	–	–	–
7–14 years	–	–	–	–	3.30	0.49	4.30
12–14 years	6.96	8.15	–	3.3	–	–	–
14–16 years	15.56	19.3	0.900	4.3	–	–	–
16–18 years	–	32.0	–	8.8	–	–	–
14–20 years	–	–	–	–	6.03	1.05	32.50
20–30 years	34.66	–	–	16.6	10.71	2.13	49.50

[1] ... *Including Reproduction and Morphological Development*, Biological Handbooks, Federation of American Societies

Organ weights at various ages (in grammes)[1]

	Lungs		Brain		Heart		Kidneys		Liver		Spleen	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
Newborn	51.7	50.9	353	347	19	20	24	24	124	125	8	
0–3 months	68.8	63.6	435	411	–	–	–	–	–	–	–	
3–6 months	94.1	93.3	600	534	–	–	–	–	–	–	–	
6–9 months	128.5	114.7	877	726	41	36	60	52	300	240	26	
9–12 months	142.4	142.1										
1–2 years	170.3	175.3	971	894	54	48	72	65	400	390	35	
2–3 years	245.9	244.3	1076	1012	63	62	85	75	460	450	42	
3–4 years	304.7	265.5	1179	1076	73	71	93	84	510	500	48	
4–5 years	314.2	311.7	1290	1156	83	80	100	93	555	550	53	
5–6 years	260.6	319.9	1275	1206	95	90	106	102	595	590	58	
6–7 years	399.5	357.5	1313	1225	103	100	112	112	630	635	62	
7–8 years	365.4	404.4	1338	1265	110	113	120	123	665	685	64	
8–9 years	405.0	382.1	1294	1208	122	126	128	135	715	745	68	
9–10 years	376.4	358.4	1360	1226	132	140	138	148	770	810	73	
10–11 years	474.5	571.2	1378	1247	144	154	150	163	850	880	82	
11–12 years	465.6	535.0	1348	1259	157	168	164	180	950	960	91	[illegible]
12–13 years	458.8	681.7	1383	1256	180	188	178	195	1050	1080	101	[illegible]
13–14 years	504.5	602.3	1382	1243	202	207	196	210	1150	1180	111	[illegible]
14–15 years	692.8	517.0	1356	1318	238	226	212	222	1240	1270	121	[illegible]
15–16 years	691.7	708.8	1407	1271	258	238	229	230	1315	1330	135	[illegible]
16–17 years	747.3	626.5	1419	1300	282	243	244	236	1380	1360	145	[illegible]
17–18 years	776.9	694.5	1409	1254	300	247	260	240	1450	1380	152	[illegible]
18–19 years	874.7	654.9	1426	1312	310	250	270	244	1510	1395	157	[illegible]
19–20 years	1035.6	785.2	1430	1294	318	251	282	247	1580	1405	160	[illegible]
20–21 years	953.0	792.8	–	–	322	252	290	248	1630	1415	162	[illegible]

Weights of endocrine organs (in grammes) (values are for both sexes)[1]

	Adrenals	Pituitary	Thymus	Pancreas	Thyroid
Newborn	9.04	–	10.9	2.77	2.09
2–14 days	5.19	–	–	–	–
0–1 month	–	–	–	2.42	–
1–2 months	–	–	–	2.63	–
0–3 months	–	–	–	–	1.71
2–3 months	–	–	–	4.46	–
0–6 months	–	0.113	–	–	–
3–6 months	3.91	–	–	5.38	2.11
1 day to 12 months	–	–	19.5	–	–
6–12 months	4.73	0.127	–	9.24	2.04
1–2 years	3.56	0.148	–	13.54	2.53
1–3 years	–	–	23.0	–	–
2–3 years	–	–	–	–	3.40
2–4 years	–	–	–	19.44	–
2–5 years	4.71	0.194	–	–	–
3–5 years	–	–	28.0	–	–
4–6 years	–	–	–	22.44	5.2
6–8 years	–	–	–	28.46	7.0
5–10 years	5.19	0.257	28.5	–	–
8–10 years	–	–	–	26.53	9.3
10–12 years	–	–	–	29.25	8.6
12–14 years	–	–	–	–	14.8
10–15 years	7.00	0.380	29.5	–	–
14–16 years	–	–	–	–	14.4
16–18 years	–	–	–	–	16.6
15–20 years	10.00	0.556	21.0	68.33	–
18–20 years	–	–	–	–	18.3
20–25 years	–	–	18.6	–	–

Weights of reproductive organs (in grammes)[1]

	Testes	Testes and epididymides	Seminal vesicles	Prostate	Ovaries	Uterine tubes	Uterus
Newborn	0.85	0.91	0.050	0.82	0.33	0.29	3.90
0–1 year	1.03	1.33	0.052	0.9	0.62	0.26	1.42
1–2 years	–	–	–	–	0.84	0.29	1.50
1–3 years	1.48	1.82	–	1.2	–	–	–
2–4 years	–	–	–	–	1.12	–	2.30
3–5 years	1.64	1.76	–	1.1	–	–	–
4–7 years	–	–	–	–	1.90	–	2.80
5–10 years	1.67	2.24	0.099	1.3	–	–	–
10–12 years	2.00	4.00	0.120	1.9	–	–	–
7–14 years	–	–	–	–	3.30	0.49	4.30
12–14 years	6.96	8.15	–	3.3	–	–	–
14–16 years	15.56	19.3	0.900	4.3	–	–	–
16–18 years	–	32.0	–	8.8	–	–	–
14–20 years	–	–	–	–	6.03	1.05	32.50
20–30 years	34.66	–	–	16.6	10.71	2.13	49.50

[1] ... Biological Handbooks, Federation of American Societi...

Height (in shoes)		Average weights in pounds and *kilogrammes* (in indoor clothing)															
		15–16 years		17–19 years		20–24 years		25–29 years		30–39 years		40–49 years		50–59 years		60–69 years	
in	*cm*	lb	*kg*	lb	*kg*	lb	*kg*	lb	*kg*	lb	*kg*	lb	*kg*	lb	*kg*	lb	*kg*
Men																	
0	*152.4*	98	*44.5*	113	*51.3*	122	*55.3*	128	*58.1*	131	*59.4*	134	*60.8*	136	*61.7*	133	*60.3*
0½	*153.7*	100	*45.4*	114.5	*51.9*	123.5	*56*	129.5	*58.7*	132.5	*60.1*	135.5	*61.5*	137.5	*62.4*	134.5	*61*
1	*154.9*	102	*46.3*	116	*52.6*	125	*56.7*	131	*59.4*	134	*60.8*	137	*62.1*	139	*63*	136	*61.7*
1½	*156.2*	104.5	*47.4*	117.5	*53.3*	126.5	*57.4*	132.5	*60.1*	135.5	*61.5*	138.5	*62.8*	140.5	*63.7*	137.5	*62.4*
2	*157.5*	107	*48.5*	119	*54*	128	*58.1*	134	*60.8*	137	*62.1*	140	*63.5*	142	*64.4*	139	*63*
2½	*158.8*	109.5	*49.7*	121	*54.9*	130	*59*	136	*61.7*	139	*63*	142	*64.4*	143.5	*65.1*	140.5	*63.7*
3	*160*	112	*50.8*	123	*55.8*	132	*59.9*	138	*62.6*	141	*64*	144	*65.3*	145	*65.8*	142	*64.4*
3½	*161.3*	114.5	*51.9*	125	*56.7*	134	*60.8*	139.5	*63.3*	143	*64.9*	146	*66.2*	147	*66.7*	144	*65.3*
4	*162.6*	117	*53.1*	127	*57.6*	136	*61.7*	141	*64*	145	*65.8*	148	*67.1*	149	*67.6*	146	*66.2*
4½	*163.8*	119.5	*54.2*	129	*58.5*	137.5	*62.4*	142.5	*64.6*	147	*66.7*	150	*68*	151	*68.5*	148	*67.1*
5	*165.1*	122	*55.3*	131	*59.4*	139	*63*	144	*65.3*	149	*67.6*	152	*68.9*	153	*69.4*	150	*68*
5½	*166.4*	124.5	*56.5*	133	*60.3*	140.5	*63.7*	146	*66.2*	151	*68.5*	154	*69.9*	155	*70.3*	152	*68.9*
6	*167.6*	127	*57.6*	135	*61.2*	142	*64.4*	148	*67.1*	153	*69.4*	156	*70.8*	157	*71.2*	154	*69.9*
6½	*168.9*	129.5	*58.7*	137	*62.1*	143.5	*65.1*	149.5	*67.8*	155	*70.3*	158.5	*71.9*	159.5	*72.3*	156.5	*71*
7	*170.2*	132	*59.9*	139	*63*	145	*65.8*	151	*68.5*	157	*71.2*	161	*73*	162	*73.5*	159	*72.1*
7½	*171.5*	134.5	*61*	141	*64*	147	*66.7*	153	*69.4*	159	*72.1*	163	*73.9*	164	*74.4*	161	*73*
8	*172.7*	137	*62.1*	143	*64.9*	149	*67.6*	155	*70.3*	161	*73*	165	*74.8*	166	*75.3*	163	*73.9*
8½	*174*	139.5	*63.3*	145	*65.8*	151	*68.5*	157	*71.2*	163	*73.9*	167	*75.8*	168	*76.2*	165.5	*75.1*
9	*175.3*	142	*64.4*	147	*66.7*	153	*69.4*	159	*72.1*	165	*74.8*	169	*76.7*	170	*77.1*	168	*76.2*
9½	*176.5*	144	*65.3*	149	*67.6*	155	*70.3*	161	*73*	167.5	*76*	171.5	*77.8*	172.5	*78.2*	170.5	*77.3*
10	*177.8*	146	*66.2*	151	*68.5*	157	*71.2*	163	*73.9*	170	*77.1*	174	*78.9*	175	*79.4*	173	*78.5*
10½	*179.1*	148	*67.1*	153	*69.4*	159	*72.1*	165	*74.8*	172	*78*	176	*79.8*	177.5	*80.5*	175.5	*79.6*
11	*180.3*	150	*68*	155	*70.3*	161	*73*	167	*75.8*	174	*78.9*	178	*80.8*	180	*81.6*	178	*80.8*
11½	*181.6*	152	*68.9*	157.5	*71.4*	163.5	*74.2*	169.5	*76.9*	176.5	*80.1*	180.5	*81.9*	182.5	*82.8*	180.5	*81.9*
0	*182.9*	154	*69.9*	160	*72.6*	166	*75.3*	172	*78*	179	*81.2*	183	*83*	185	*83.9*	183	*83*
0½	*184.2*	156.5	*71*	162	*73.5*	168	*76.2*	174.5	*79.2*	181	*82.1*	185	*83.9*	187	*84.8*	185.5	*84.1*
1	*185.4*	159	*72.1*	164	*74.4*	170	*77.1*	177	*80.3*	183	*83*	187	*84.8*	189	*85.7*	188	*85.3*
1½	*186.7*	161.5	*73.3*	166	*75.3*	172	*78*	179.5	*81.4*	185.5	*84.1*	189.5	*86*	191.5	*86.9*	190.5	*86.4*
2	*188*	164	*74.4*	168	*76.2*	174	*78.9*	182	*82.6*	188	*85.3*	192	*87.1*	194	*88*	193	*87.5*
2½	*189.2*	166.5	*75.5*	170	*77.1*	176	*79.8*	184	*83.5*	190.5	*86.4*	194.5	*88.2*	196.5	*89.1*	195.5	*88.7*
3	*190.5*	169	*76.7*	172	*78*	178	*80.8*	186	*84.4*	193	*87.5*	197	*89.4*	199	*90.3*	198	*89.8*
3½	*191.8*	–	–	174	*78.9*	179.5	*81.4*	188	*85.3*	196	*88.9*	200	*90.7*	202	*91.6*	201	*91.2*
4	*193*	–	–	176	*79.8*	181	*82.1*	190	*86.2*	199	*90.3*	203	*92.1*	205	*93*	204	*92.5*
Women																	
10	*147.3*	97	*44*	99	*44.9*	102	*46.3*	107	*48.5*	115	*52.2*	122	*55.3*	125	*56.7*	127	*57.6*
10½	*148.6*	98.5	*44.7*	100.5	*45.6*	103.5	*46.9*	108.5	*49.2*	116	*52.6*	123	*55.8*	126	*57.2*	128	*58.1*
11	*149.9*	100	*45.4*	102	*46.3*	105	*47.6*	110	*49.9*	117	*53.1*	124	*56.2*	127	*57.6*	129	*58.5*
11½	*151.1*	101.5	*46*	103.5	*46.9*	106.5	*48.3*	111.5	*50.6*	118.5	*53.8*	125.5	*56.9*	128.5	*58.3*	130	*59*
0	*152.4*	103	*46.7*	105	*47.6*	108	*49*	113	*51.3*	120	*54.4*	127	*57.6*	130	*59*	131	*59.4*
0½	*153.7*	105	*47.6*	107	*48.5*	110	*49.9*	114.5	*51.9*	121.5	*55.1*	128.5	*58.3*	131.5	*59.6*	132.5	*60.1*
1	*154.9*	107	*48.5*	109	*49.4*	112	*50.8*	116	*52.6*	123	*55.8*	130	*59*	133	*60.3*	134	*60.8*
1½	*156.2*	109	*49.4*	111	*50.3*	113.5	*51.5*	117.5	*53.3*	124.5	*56.5*	131.5	*59.6*	134.5	*61*	135.5	*61.5*
2	*157.5*	111	*50.3*	113	*51.3*	115	*52.2*	119	*54*	126	*57.2*	133	*60.3*	136	*61.7*	137	*62.1*
2½	*158.8*	112.5	*51*	114.5	*51.9*	116.5	*52.8*	120.5	*54.7*	127.5	*57.8*	134.5	*61*	138	*62.6*	139	*63*
3	*160*	114	*51.7*	116	*52.6*	118	*53.5*	122	*55.3*	129	*58.5*	136	*61.7*	140	*63.5*	141	*64*
3½	*161.3*	115.5	*52.4*	118	*53.5*	119.5	*54.2*	123.5	*56*	130.5	*59.2*	138	*62.6*	142	*64.4*	143	*64.9*
4	*162.6*	117	*53.1*	120	*54.4*	121	*54.9*	125	*56.7*	132	*59.9*	140	*63.5*	144	*65.3*	145	*65.8*
5 4½	*163.8*	119	*54*	122	*55.3*	123	*55.8*	127	*57.6*	133.5	*60.6*	141.5	*64.2*	146	*66.2*	147	*66.7*
5 5	*165.1*	121	*54.9*	124	*56.2*	125	*56.7*	129	*58.5*	135	*61.2*	143	*64.9*	148	*67.1*	149	*67.6*
5 5½	*166.4*	123	*55.8*	125.5	*56.9*	127	*57.6*	131	*59.4*	137	*62.1*	145	*65.8*	150	*68*	151	*68.5*
5 6	*167.6*	125	*56.7*	127	*57.6*	129	*58.5*	133	*60.3*	139	*63*	147	*66.7*	152	*68.9*	153	*69.4*
5 6½	*168.9*	126.5	*57.4*	128.5	*58.3*	130.5	*59.2*	134.5	*61*	140.5	*63.7*	149	*67.6*	154	*69.9*	155	*70.3*
5 7	*170.2*	128	*58.1*	130	*59*	132	*59.9*	136	*61.7*	142	*64.4*	151	*68.5*	156	*70.8*	157	*71.2*
5 7½	*171.5*	130	*59*	132	*59.9*	134	*60.8*	138	*62.6*	144	*65.3*	153	*69.4*	158	*71.7*	159	*72.1*
5 8	*172.7*	132	*59.9*	134	*60.8*	136	*61.7*	140	*63.5*	146	*66.2*	155	*70.3*	160	*72.6*	161	*73*
5 8½	*174*	134	*60.8*	136	*61.7*	138	*62.6*	142	*64.4*	148	*67.1*	157	*71.2*	162	*73.5*	163	*73.9*
5 9	*175.3*	136	*61.7*	138	*62.6*	140	*63.5*	144	*65.3*	150	*68*	159	*72.1*	164	*74.4*	165	*74.8*
5 9½	*176.5*	–	–	140	*63.5*	142	*64.4*	146	*66.2*	152	*68.9*	161.5	*73.3*	166.5	*75.5*	–	–
5 10	*177.8*	–	–	142	*64.4*	144	*65.3*	148	*67.1*	154	*69.9*	164	*74.4*	169	*76.7*	–	–
5 10½	*179.1*	–	–	144.5	*65.5*	146.5	*66.5*	150.5	*68.3*	156.5	*71*	166.5	*75.5*	171.5	*77.8*	–	–
5 11	*180.3*	–	–	147	*66.7*	149	*67.6*	153	*69.4*	159	*72.1*	169	*76.7*	174	*78.9*	–	–
5 11½	*181.6*	–	–	149.5	*67.8*	151.5	*68.7*	155.5	*70.5*	161.5	*73.3*	171.5	*77.8*	177	*80.3*	–	–
6 0	*182.9*	–	–	152	*68.9*	154	*69.9*	158	*71.7*	164	*74.4*	174	*78.9*	180	*81.6*	–	–

[1] Insured persons in the United States (Society of Actuaries *Build and Blood Pressure Study*, vol 1, Chicago, 1959, page 16, with interpolations by the editors of these *Scientific Tables*). Compare the *desirable* weights in a similar population given in the table on page 712

Desirable Weights of Adults[7]

Height (in shoes)			Desirable weight in pounds and *kilogrammes* (in indoor clothing), ages 25 and over					
			Small frame		Medium frame		Large frame	
ft	in	*cm*	lb	*kg*	lb	*kg*	lb	*k*
				Men				
5	2	*157.5*	112–120	*50.8–54.4*	118–129	*53.5–58.5*	126–141	*57.2–*
5	3	*160*	115–123	*52.2–55.8*	121–133	*54.9–60.3*	129–144	*58.5–*
5	4	*162.6*	118–126	*53.5–57.2*	124–136	*56.2–61.7*	132–148	*59.9–*
5	5	*165.1*	121–129	*54.9–58.5*	127–139	*57.6–63*	135–152	*61.2–*
5	6	*167.6*	124–133	*56.2–60.3*	130–143	*59 –64.9*	138–156	*62.6–*
5	7	*170.2*	128–137	*58.1–62.1*	134–147	*60.8–66.7*	142–161	*64.4–*
5	8	*172.7*	132–141	*59.9–64*	138–152	*62.6–68.9*	147–166	*66.7–*
5	9	*175.3*	136–145	*61.7–65.8*	142–156	*64.4–70.8*	151–170	*68.5–*
5	10	*177.8*	140–150	*63.5–68*	146–160	*66.2–72.6*	155–174	*70.3–*
5	11	*180.3*	144–154	*65.3–69.9*	150–165	*68 –74.8*	159–179	*72.1–*
6	0	*182.9*	148–158	*67.1–71.7*	154–170	*69.9–77.1*	164–184	*74.4–*
6	1	*185.4*	152–162	*68.9–73.5*	158–175	*71.7–79.4*	168–189	*76.2–*
6	2	*188*	156–167	*70.8–75.7*	162–180	*73.5–81.6*	173–194	*78.5–*
6	3	*190.5*	160–171	*72.6–77.6*	167–185	*75.7–83.5*	178–199	*80.7–*
6	4	*193*	164–175	*74.4–79.4*	172–190	*78.1–86.2*	182–204	*82.7–*
				Women				
4	10	*147.3*	92– 98	*41.7–44.5*	96–107	*43.5–48.5*	104–119	*47.2–5*
4	11	*149.9*	94–101	*42.6–45.8*	98–110	*44.5–49.9*	106–122	*48.1–5*
5	0	*152.4*	96–104	*43.5–47.2*	101–113	*45.8–51.3*	109–125	*49.4–5*
5	1	*154.9*	99–107	*44.9–48.5*	104–116	*47.2–52.6*	112–128	*50.8–5*
5	2	*157.5*	102–110	*46.3–49.9*	107–119	*48.5–54*	115–131	*52.2–5*
5	3	*160*	105–113	*47.6–51.3*	110–122	*49.9–55.3*	118–134	*53.5–6*
5	4	*162.6*	108–116	*49 –52.6*	113–126	*51.3–57.2*	121–138	*54.9–6*
5	5	*165.1*	111–119	*50.3–54*	116–130	*49 –59*	125–142	*49.4–6*
5	6	*167.6*	114–123	*51.7–55.8*	120–135	*54.4–61.2*	129–146	*58.5–6*
5	7	*170.2*	118–127	*53.5–57.6*	124–139	*56.2–63*	133–150	*60.3–6*
5	8	*172.7*	122–131	*55.3–59.4*	128–143	*58.1–64.9*	137–154	*62.1–6*
5	9	*175.3*	126–135	*57.2–61.2*	132–147	*59.9–66.7*	141–158	*64 –7*
5	10	*177.8*	130–140	*59 –63.5*	136–151	*61.7–68.5*	145–163	*65.8–7*
5	11	*180.3*	134–144	*60.8–65.3*	140–155	*63.5–70.3*	149–168	*67.6–7*
6	0	*182.9*	138–148	*62.6–67.1*	144–159	*65.3–72.1*	153–173	*69.4–7*

[7] Weights of insured persons in the United States associated with lowest mortality (*Statist. Bull. Metrop. Life Insur. Co.*, 40, Nov.–Dec. 1959).

of particular enzymes[1].

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tropins of the anterior pituitary[1,2]

stimulating hormone

llicle-ripening hormone)

ing hormone

rstitial cell-stimulating hormone = ICSH, corpus luteum-hormone)

try

of various human gonadotropin preparations[5]

Origin	FSH preparations		
	Activity (IU/mg)	LH content (IU/mg)	Prepared by
tary	1000	< 10	BUTT
opausal urine	597	11	DONINI
	789	< 0 03	STEVENS
: urine	59 5	24 2	DONINI
Origin	**LH preparations**		
	Activity (IU/mg)	*FSH content (IU/mg)*	*Prepared by*
itary	7500	< 1	HARTREE
iopausal urine	447	18 9	DONINI
le urine	53 6	6 7	DONINI

methods of assay

: following reference preparations are available[6]

ternational Reference Preparation of Human Menopausal Go-idotropin (IRP-HMG), known previously as HMG-24

... Reference Preparation of Human Menopaus...

Human Pituitary Gonadotropin (NIH-HPG-UB) of the Nationa...

S1).

Human Pituitary Gonadotropin: An International Reference Preparation is in course of development

Conversion factors for reference preparations (as mg or IU equivalent to 1 mg of 2nd IRP-HMG)[4]

Reference preparation	*FSH**	*LH***
2nd IRP-HMG	1	1
1st IRP-HMG	56	16
NIH-FSH-S1	0 31	–
NIH-LH-S1	–	0.0053
International Unit	8	8

* Assayed by the ovarian augmentation method in rodents
** Assayed by the rat ovarian ascorbic acid depletion method

There is a considerable literature on the assay and extraction of gonadotropins in body fluids[6,7] The following methods are in common use

Total gonadotropic activity Increase in the weight of the uterus in

LH activity Increase in ventral prostatic weight in immature hypophysectomized rats[11], depletion of ovarian ascorbic acid[12] or cholesterol[13] in pseudo-pregnant immature rats after intravenous

teria of immunological methods for both hormones remain to be established

Biosynthesis, secretion, metabolism

have been detected in the urine of prepuberal children[26]. In women, gonadotropin excretion shows characteristic fluctuations during the menstrual cycle with a maximum during the ovulatory phase shortly before the rise in basal temperature[27]. LH is present in the urine in all phases of the cycle and like total gonadotropin excretion rises to a maximum at midcycle[28-30]. FSH is also found in the urine in all phases of the cycle but the excretion is not subject to any marked rhythmic change[28,29]. After the menopause gonadotropin excretion is increased, with wide daily variations, as a result of the almost complete cessation of ovarian oestrogen secretion[31]. In male urine FSH and LH are present in about the same proportion as in menopausal urine[29].

Total gonadotropin excretion in urine

	Mean	Range	s	Reference
	mg 1st IRP-HMG/24 h			
Men, 18–40 years	7.7	3.8–18.1	–	47
Women, 18–35 years	4.9	2.7–7.1	–	47
Girls, 14–15 years..........	0.8	–	–	47
Girls, 10 years.............	0.3	–	–	47
Boy, 8½ years.............	0.5	–	–	47
	U 1st IRP-HMG/24 h			
Women, menstruating......	9.0	3.0–15.7	–	48
Women, proliferation phase .	9.2	2.8–30.4	–	48
Women, ovulation phase ...	10.5	2.8–31.6	–	48
Women, luteal phase	7.4	2.9–14.9	–	48
Women, postmenopausal ...	76	35–158*	–	49
Men, 20–60 years	11	5–23*	–	50

* 95 % range.

Gonadotropin assay in urine enables primary gonadal insufficiency (increased excretion) to be distinguished from secondary gonadal insufficiency due to disturbance of pituitary function (decreased excretion).

The urine of both children and adults contains a gonadotropin-inhibiting factor, but the precise physiological significance of this substance is not known[32,43].

Regulation of gonadotropin secretion. Gonadotropin secretion is regulated by neurohumoral factors from the hypothalamus, the so-called 'gonadotropin-releasing factors' (GRF)[33]. These reach the cells of the anterior lobe of the pituitary via the portal circulation of the gland[34]. At present the best-known factor is LH-RF, a polypeptide of molecular weight between 1200 and 2500[35]. When given to rats this factor causes a rise in the plasma LH level[36]. Formation of LH-RF is inhibited by oestrogens and, at high dosage, by progesterone and testosterone[35]. Direct inhibition of LH release through the action of oestrogens on the pituitary may also occur[37]. Inhibition of FSH-RF formation appears to require larger amounts of oestrogens than that of LH-RF formation[38] and is also caused by testosterone[39]. The regulation of gonadotropin secretion is subject to the influence of nervous impulses of central and peripheral origin[40,41]. The interaction of the gonadal steroids with the hypothalamus and pituitary not only takes the form of a negative feedback mechanism but in some circumstances may result in stimulation of these glands (positive feedback)[2,40].

Biological activity

The gonadotropins act directly on the gonads of both sexes and indirectly on the male and female reproductive organs by stimulating the secretion of gonadal steroids. In both sexes FSH is responsible for maintaining gametogenesis, LH for stimulating the interstitial ovarian tissue, ovulation, corpus luteum formation and the production of androgens in the cells of LEYDIG. The interplay of the various regulatory mechanisms in the course of the menstrual cycle is still not fully understood. Together with LH, FSH induces growth of the follicle and secretion of oestrogens. Sudden release of LH results in ovulation and suppresses oestrogen secretion, but such a release can be inhibited by high blood levels of oestrogens and progestational substances; this is one reason for their use in ovulation-inhibiting preparations. Adminis FSH preparations from the human pituitary tissue fol HCG has repeatedly been shown to induce ovulation[42].

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Corticotropin[1,2]

(corticotropic hormone, adrenocorticotropin, adrenocorticotropic hormone = ACTH)

Chemistry[1,3]

The corticotropins isolated from the pituitary gland of various animal species are all single-chain peptides made up of 39 amino-acid residues. Structurally very similar, they differ only in part of the amino-acid sequence of the molecule (see the table below). The structure of the β-corticotropin from pigs was elucidated in 1956[4], and in 1963 its complete synthesis was reported[5]; it has a molecular weight of 4567. In the pituitary, ACTH probably occurs not only in the free state but also in a protein-bound form[6]. In 1967 the amino-acid chain characteristic of human α-ACTH was synthesized[44].

Possession of the complete amino-acid chain of the natural hormones is not an essential condition for corticotropic biological activity; very active peptides have been synthesized containing only the first 20–24 amino-acid residues of ACTH. Part of the amino-acid sequence of the corticotropins is identical with part of the sequence in the melanotropins (see page 721), and in fact the corticotropins have some melanocyte-stimulating activity. Whereas the biological activity of ACTH rests in the first 20–24 amino acids, it is the remaining part of the chain that is responsible for the immunological properties[7]. An ectopic ACTH is formed by some nonpituitary tumours and has been shown to be very similar to pituitary ACTH both chemically and immunologically[8].

Lipotropin

During the isolation of ACTH from the pituitary two further biologically active peptides have recently come to light. These were found to consist of 59 and 90 amino-acid residues respectively and on account of their lipolytic activity have been named γ- and β-lipotropins (lipotropic hormone, LPH)[9]. LPH possesses only slight corticotropic activity but resembles ACTH in melanocyte-stimulating activity.

Units, methods of assay[10,11]

1 International Unit (IU) of corticotropin is equal to 1 mg of 3rd International Standard (see page 762). Of the many methods of determining the hormone, those most suitable for clinical purposes are the ascorbic acid depletion test of SAYERS et al.[12] (diminution in the ascorbic acid content of the adrenals of hypophysectomized rats after administration of ACTH) and the LIPSCOMB and NELSON[13] (increase in the corticosteroid cont the adrenal cortex of hypophysectomized rats after administ of ACTH). The activity of ACTH preparations can also be mined by the in vitro method of SAFFRAN and SCHALLY[14] (cc steroid formation in adrenal preparations from rats). Radioi nological methods of determining ACTH in body fluids recently been described[15].

Biosynthesis, secretion, metabolism

The site of ACTH formation in the pituitary is not known certainty, but it is probably the chromophobic β³ cells of tl terior lobe[16], though the hormone is also found in the basopl cells of the anterior and posterior lobes of the gland[17]. ACT been shown to be already present in the pituitary of the 16 v foetus[18]. The adult pituitary contains 7–38 IU of ACTH[6]. on the ACTH content of blood vary with the methods of c mination and extraction; recent work[19,20] indicates that the l level in man at rest lies between 1 mIU and 10 mIU per litre pl Radioimmunoassay has shown plasma levels of 10–80 ng/l (in t of porcine ACTH; 1 mIU ≈ 10 ng)[15]. The level is higher in stre in untreated adrenocortical insufficiency, in the advanced of CUSHING's disease and particularly following bilateral adr ectomy[10,11,22]. In man, the blood level at rest is subject to a and-night rhythm, with higher values in the morning and l values in the evening[20,23]. Little is known of the fate of the A(circulating in the blood; exogenous ACTH is reported to h half-life of 5 min or less[24], and in rats 75% of the endogenous culating hormone was found to have disappeared within 3 mi Peptidases, which may be responsible for the breakdown of AC

Variation of the cortisol and ACTH contents of the plasma with age[4]

	Cortisol (μg/l)		ACTH (mIU/l)	
	Mean	*s*	Mean	*s*
1–5 years	244	64	1.9	0.8
6–10 years	193	58	1.6	0.4
11–15½ years ..	165	66	2.5	1.2
16–41 years	164	44	2.2	1.1

Structure and biological activity of corticotropins

	Amino-acid sequence*	ACTH activity (IU/mg)	
		in vitro†	in vivo†
α-ACTH (cattle)	NH$_2$ Ser·[A]·Asp·Gly·Glu·Ala·Glu·Asp·Ser·Ala·Glu·[B]·Phe 1 25 26 27 28 29 30 31 32 33 39	140	–
α-ACTH (sheep)	NH$_2$ Ser·[A]·Ala·Gly·Glu·Asp·Asp·Glu·Ala·Ser·Glu·[B]·Phe 1 25 26 27 28 29 30 31 32 33 39	177	100–150
α-ACTH (pig) .... (corticotropin A**, β-corticotropin)	NH$_2$ Ser·[A]·Asp·Gly·Ala·Glu·Asp·Glu·Leu·Ala·Glu·[B]·Phe 1 25 26 27 28 29 30 31 32 33 39	90–150	80–150
α-ACTH (man)	NH$_2$ Ser·[A]·Asp·Ala·Gly·Glu·Asp·Glu·Ser·Ala·Glu·[B]·Phe 1 25 26 27 28 29 30 31 32 33 39	52	26
[illegible]tropin (synthetic)	As α-ACTH (pig)	–	115

Thyrotropin[1,2]

(thyrotropic hormone, thyroid-stimulating hormone = TSH)

Chemistry[3]

Bovine and human thyrotropins are glycoproteins of molecular weight ca. 28000; in addition to amino acids the molecule contains glucosamine, galactosamine and mannose. A highly purified but unstable preparation from the human pituitary had an activity of 20 IU/mg[3]. Bovine TSH is biologically active in all vertebrates but the activity varies with the species. A substance similar to TSH has been isolated from mammalian pituitaries and given the name heterothyrotropic factor (HTF)[4]; it has little TSH activity in [illegible] but is highly active in fish.

[illegible]

[illegible] 1 Unit (IU) is equal to 13.5 mg of the 1st Interna[illegible]d (see page 762). 1 IU = 1 USP Unit = ca. 10 Junkmann-Units (JSU).

[illegible] of assay[2,3,5]

TSH activity can be determined in vivo or in vitro by means of the histological or physiological effects on the thyroid. In vitro methods in common use are those of Bakke et al.[6] (weight change of thyroid slices) and of Kirkham[7] and Bottari et al.[8] (release of ^{131}I from thyroid slices). In body fluids, TSH concentration can now also be measured by radioimmunoassay[9,10].

Biosynthesis, secretion, metabolism

TSH is formed in the basophile β^2-cells of the anterior pituitary[11]. The rate of secretion is regulated by the concentration of thyroid hormone in the circulating blood through a negative feedback mechanism (see page 727), a rise in the blood level of free thyroxine depressing TSH secretion, a fall accelerating it. Regulation of TSH secretion involves a neurohumoral mechanism depending on the formation of a thyrotropin-releasing factor (TRF)[12]. This neurohormone, probably a weakly basic polypeptide[13], is secreted by the nuclei of the anterior hypothalamus and discharged into the portal arteries of the anterior pituitary, where it stimulates the release and possibly also the synthesis of TSH[14]. In adults the rate of secretion of TSH has been estimated at 50–225 μg/24 h[15], corresponding to a half-life for TSH of 39–68 min.

Serum TSH levels. There is disagreement over the absolute levels[2,3]. Serum concentrations of less than 3 μg/l have been measured by radioimmunoassay in 50 euthyroid subjects, 10 hypophysectomized subjects and 12 pregnant women[9]; in the same study the levels in patients with hypothyroidism were 3–100 times higher, in those with hyperthyroidism within the normal range. The serum level in children is the same as in adults[16,26] but higher in the newborn[26] and old people[16]. The high plasma levels in hypothyroid patients are due to prolonged survival of TSH in the circulation and increased pituitary secretion of the hormone[15].

Whether TSH is excreted in measurable amount in the urine is still uncertain.

Long-acting thyroid stimulator (= LATS; thyroid-stimulating globulin = TSG). This factor is probably involved in the pathogenesis of Graves' disease[17,18]. In the bioassay of TSH its presence is revealed by the long duration of its stimulating action compared to TSH. LATS appears to be a γG-globulin[19]; it is formed in the lymphatic system and has a half-life in the rat of 7½ h[17].

Exophthalmos is certainly not due to TSH and probably not to LATS; a possible cause is a substance secreted by the pituitary[20] (EPS = exophthalmos-producing substance).

Biological activity

TSH brings about both histological and metabolic changes in the thyroid. The former comprise a diminution in the colloid content and enlargement of the epithelial cells, while under long-continued TSH stimulation the vessels become more numerous and larger and the gland becomes hypertrophic. The metabolic changes appear within 5–30 min of administering TSH[21] and include increased oxygen consumption, glucose oxidation, phospholipid turnover, RNA synthesis and sodium uptake as well as stimulation of the various steps in the formation and release of thyroid hormone, particularly the organic binding of iodine[22], the formation of iodothyronines from iodotyrosines[23], the liberation of thyroid hormone from thyroglobulin[24], and the release of iodine from iodotyrosines[22]. The effects of LATS on the thyroid are similar to those of TSH but are delayed[17,25].

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Prolactin[1,2]

(lactogenic hormone, luteotropin, mammotropin, prolactin hormone = PH, luteotropic hormone = LTH, luteomammotropic hormone = LMTH)

Chemistry

Prolactin as isolated from the anterior pituitary of sheep, cattle and pigs is a polypeptide of molecular weight ca. 25000[3,4]. The prolactin molecule from sheep and cattle contains 211 amino-acid residues arranged as a single chain[3]; that from pigs has a considerably higher cysteine content[4].

Whether a primate prolactin exists is still uncertain[5]. Growth hormone from man and monkeys has been shown to have prolactin-like activity, and this activity is intrinsic to the growth hormone molecule. Other studies indicate that human growth hormone and prolactin are potentially separable[6]. A high prolactin activity but low growth hormone activity has been demonstrated in a human pituitary tumour[21], thus providing further evidence that the two hormones are not identical.

Luteotropin, formerly thought to be a distinct hormone, is now regarded as identical with prolactin.

Units, methods of assay

1 International Unit (IU) is equal to 0.04545 mg of the 2nd International Standard (see page 762), obtained from the anterior pituitary of sheep.

Biological assay[5,7,8]. Proliferation test on the pigeon crop[9]. Determination of mammotropic activity in rabbits[10] or mice[11]. Determination of luteotropic activity in rats[12] or mice[13]. Immunological methods have been devised[14] but have not yet found clinical application.

Biosynthesis, secretion, metabolism[2]

Prolactin is formed in the acidophile cells (staining with azocarmine or erythrosin) of the anterior pituitary. In mammals these cells exhibit increasing secretory activity during pregnancy and particularly lactation. Data on prolactin activity in the blood and urine of both men and women are to be found in the literature but in view of the difficulties of hormone extraction and determination they are of questionable reliability[8].

Regulation of prolactin secretion[2]. In contrast to its effect on the secretion of the other anterior pituitary hormones, the hypothala-

s[19]. The similar effect produced by large doses of progester-
ndrogens and corticosteroids is probably an indirect one

gical activity[2]

ats and mice, prolactin has a luteotropic effect similar to that gonadotropins, while its mammotropic and lactogenic effects

mammals, prolactin plays an important part in the growth of nammary glands. In ovarectomized rats, administration of ictin together with growth hormone results in complete

inues as a result of the suckling stimulus, so that lactation is itained

i male guinea-pigs and rats, prolactin has been reported to note the growth of the prostate and seminal vesicles, but the siological role played by the hormone in the male animal re- is obscure.

i man, prolactin from sheep has effects similar to those of growth none of human origin[20].

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HGH is fairly stable, so that pituitaries removed at autopsy can be kept for months with little loss of activity if stored in acetone or at very low temperature Hormone isolated by the usual methods is not homogeneous and can be separated into components, *for example by gel filtration[4] into two and by electrophoresis[5] into* three components

The growth hormones from different species also differ immu-

Growth hormone from various species[34]

	Mol weight	No of amino acids	N terminal sequence	C terminal sequence	Iso-elec-tric point
Sheep	47800	430	Phe and Ala	Thr Ala Phe	6 8
Ox ..	45000	416	Phe Ala·Thr·and Ala Phe Ala	Cys Ala Phe	6 8
Pig . .	41600	–	Phe Pro Ala	Cys Ala Phe	6 3
Whale.	39900	340	Phe Lys (?)	Leu Ala Phe	6 2
Monkey	25400	220	Phe·Thr· (?)	Ala Gly Phe	5 5
Man .	21500	188	Phe Pro Thr·	Cys Gly Phe	4 9

Units, methods of assay[5]

Indirectly, growth hormone can be determined by means of the dose-dependent incorporation of tagged sulphur into the rib cartilage of hypophysectomized rats[12] This method measures the so-called *sulphation factor*, a component of human serum not identical with HGH but closely related to it

Biosynthesis, secretion, metabolism

Growth hormone is very probably formed in the acidophile α-

The secretion of growth hormone is to some extent regulated by the hypothalamus, probably via the formation of a 'somatotropin-releasing factor'[26] which stimulates the pituitary. In rats it has been shown that exogenous growth hormone inhibits endogenous hormone secretion, indicating the existence of a feedback mechanism[27].

Plasma levels of growth hormone (μg/l)

	Mean	Range	*s*	Reference
Cord blood	49.7	–	57.8	36
Children under 12 months	18.6	–	12.5	36
Children, 1–8 years	8.5	–	7.8	36
Children, 9–10 years	2.8	–	2.8	36
Adolescents, 11–17 years	14.0	–	13.4	36
Adults, hospitalized	0.55	–	0.68	36
Women, lactating	4.5	–	2.1	36
Women	4.91	0.9–10.6	3.32	37
Men	0.27	0.1–0.7	0.14	37

Physiological effects of growth hormone[35]

Protein metabolism	Increased protein synthesis Nitrogen retention* Phosphorus retention* Potassium retention* Diminished urea excretion* Increased intracellular amino-acid transport Increased protein synthesis at ribosomes
Lipid metabolism	Intracellular lipolysis Increased free fatty acid level in plasma* Increased oxidation of fats* Increased ketogenesis in diabetics*
Carbohydrate metabolism	Exacerbation of diabetes* Reduced response to insulin* Diminished conversion of glucose into fat in fatty tissue
Mineral metabolism	Calcium metabolism Increased intestinal absorption* Increased urinary excretion* Sodium retention* Phosphorus retention* Increased blood-phosphate level* Increased serum alkaline phosphatase level*
Organs and tissues	Acromegaly Connective tissue Stimulation of chondroitin sulphate synthesis Stimulation of collagen synthesis Increased excretion of hydroxyproline* Increase in volume of interstitial fluid

* Demonstrable in man after administration of growth hormone.

Biological activity

In man, as in other animal species, the body has a speci
quirement for growth hormone. In 6-week-old rats hypo
ectomy causes immediate cessation of growth, which recomn
immediately when the hormone is administered and continu
as long as the medication is continued. In children with pit
hypofunction growth is often retarded in even the first y
life[28] and then slows down greatly in the subsequent years
ministration of HGH to individuals with dwarfism due to
ciency of this hormone causes them to grow normally or
faster than normal[29], but animal growth hormone is inacti
this respect. One reason why hypopituitary dwarfism in some
does not respond to doses of HGH is probably the formati
antibodies against the preparation used[30]. For the therapeutic
cations of growth hormone see the literature[2,31]. Unlike ana
steroids, growth hormone causes no acceleration of the matur
of bone.

Growth hormone has many other effects on metabolism
from that on growth, as shown in the table on this page.

Growth hormone has an anabolic effect on protein metabo
with consequent decrease in urinary nitrogen excretion. The
nitrogen retention may increase initially to 3–5 g[32], whereas g
ing children, for instance, require only 0.2 g nitrogen per
Protein synthesis is probably stimulated via the ribosomes,
sumably through promotion of messenger-RNA synthesis[33].
insulin acts synergistically.

The modifications of lipid metabolism consist of a reductic
fat synthesis and mobilization of depot fat. The free fatty
content of the blood increases.

Single doses of the hormone have an effect similar to tha
insulin, namely a fall in the blood-sugar level. Over longer per
and at higher dosage, however, growth hormone reduces glu
tolerance and causes hyperglycaemia and ketosis (diabetog
effect).

Changes in mineral metabolism due to growth hormone c
prise retention of sodium, phosphorus, potassium and usually
cium. In the kidneys the rates of glomerular filtration, plasma f
and phosphate reabsorption are increased.

In cartilage, growth hormone stimulates the proliferation
columnar cells, the incorporation of phosphate and the synth
of collagen.

In experimental animals, human growth hormone has eff
similar to those of prolactin.

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lanine[3]

HPL can be determined radioimmunologically in tissue extracts and body fluids[5–8]. The site of its production is the placenta[10] and it is contained in the cytoplasm of the syncytiotrophoblast layer of this organ[9]. The hormone can already be detected in the blood and urine in the first trimester of pregnancy, with advancing gestation the plasma level rises and reaches a maximum at term[5–7]. The normal plasma level in the third trimester is 6 8 ± 2 1 mg/l[15]. High levels have been measured in diabetic pregnant women, low levels

Melanotropin[1]

(melanocyte-stimulating hormone = MSH, melanophore hormone, chromatophore hormone, pigment hormone, intermedin)

Chemistry[2,3]

Structure and biological activity of melanotropins[20]

	Amino-acid sequence	Activity (U/g)*
ACTH	Ser Tyr Ser Met Glu His Phe Arg Trp Gly Lys Pro Val Gly Lys Lys Arg Arg Pro 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	**
α MSH (porcine, bovine, equine)	CH_3CO– Ser Tyr Ser Met Glu His Phe Arg Trp Gly Lys Pro Val NH_2 1 2 3 4 5 6 7 8 9 10 11 12 13	1 0–2 0 × 10^{10}
β MSH (porcine)	Asp Glu Gly Pro Tyr Lys Met Glu His Phe Arg Trp Gly Ser Pro Pro Lys Asp 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	3 0–5 0 × 10^9
β MSH (bovine)	Asp Ser Gly Pro Tyr Lys Met Glu His Phe Arg Trp Gly Ser Pro Pro Lys Asp 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	2 0 × 10^9
β MSH (equine)	Asp Glu Gly Pro Tyr Lys Met Glu His Phe Arg Trp Gly Ser Pro Arg Lys Asp 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	1 2 × 10^9
β MSH (human)	Ala Glu Lys Lys Asp Glu Gly Pro Tyr Arg Met Glu His Phe Arg Trp Gly Ser Pro Pro Lys Asp 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22	3 3 × 10^9

* Frog skin test in vitro.

** On a molar basis naturally occurring ACTH possesses about 1% of the activity of α-MSH, ACTH acetylated at the serine end about 10%

cluding that of human β-MSH[21]. The α-corticotropin-releasing factors (see page 725) have a structure very similar to that of α-MSH.

Units, methods of assay

Methods of assay depend on the ability of the hormone to cause dispersion of the pigment (mainly melanin) in the melanocytes of amphibia. The test object is the frog[4,5] or, in vitro, its skin[6,7]. The latter reacts to a concentration as low as 10^{-11} mol MSH per litre[8]. The activity of MSH preparations is usually expressed in units based on the test of SHIZUME et al.[6], 1 unit being that amount with the same activity as 0.04 μg of the standard preparation of these workers.

Biosynthesis and secretion

MSH is probably formed in the polygonal cells of the intermediate lobe of the pituitary, which derives from RATHKE's pouch, though it is also present in the anterior and posterior lobes. In view of the structural relationship of MSH to ACTH it is likely that the former is also synthesized in the same type of anterior pituitary cell as the latter[9]. Melanotropic activity has also been detected in plasma extracts, with particularly high values in pregnancy[4,10]. In both tissue and plasma extracts it has been possible to separate melanotropic from corticotropic activity[11]. Using a radioimmunological method, β-MSH concentrations of 20–90 ng/l have been found in human plasma[12]. In frogs and rats there is evidence that MSH secretion is regulated by the blood level of MSH through a feedback mechanism; this mechanism probably causes the hypothalamus to release a factor inhibiting MSH secretion[13]. Melanotropic activity has also been found in urine; in women this varies during the course of the menstrual cycle and rises during pregnancy[10,14].

Biological activity

In cold-blooded animals MSH causes rapid expansion of the melanocytes and dispersion of the pigment (melanin) in these cells, with consequent darkening of the skin. This reversible, physiological process of pigment regulation enables the animal rapidly to adapt itself to the colour of its surroundings. In birds and mammals the pigment content of the melanocytes controls the intensity of skin coloration, a slow process known as morphological pigment regulation in which the role played by MSH is still obscure. Pigment dispersion in frogs takes place in the melanocytes of the epidermis and dermis; this effect is reversible, but only in the dermal melanocytes, by the pineal-gland factor melatonin[15] (see page 730). Morphologically, the epidermal melanocytes of the frog are similar to those of mammals. MSH apparently increases pigment formation; thus the pigment content of frogs rises under long-term treatment with MSH, and in man daily injections of α-MSH result in hyperpigmentation already visible on the second day[16]. Other effects of administering MSH to mammals are hypocalcaemia, hyperlipaemia and increases in thyroid function, pulse rate and the permeability of the blood-aqueous barrier of the eye[3,17], but whether these actions occur at physiological levels of the hormone is not known.

The mode of action of MSH is still obscure. Melanin dispersion is probably only a secondary effect of some direct change in the cell involving sodium and calcium[18]. Melanin is formed in the melanocytes from tyrosine and oxygen (see page 440) in ribosomes containing *o*-diphenol oxidase, whereby these subcellular particles undergo a gradual 'melanization'. It is conceivable that MSH has some action on the enzyme *o*-diphenol oxidase, but this has not been demonstrated[19].

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Oxytocin[1-3]

(pitocin, lactagogin) (for references see page 725)

Vasopressin[1,2]

(pitressin, antidiuretin, antidiuretic hormone = ADH)

Chemistry[4]

As isolated from the posterior pituitary of various specie[s] hormones oxytocin and vasopressin are cyclic polypeptides [...] up of 9 amino-acid residues, one disulphide bridge and one te[rmi]nal amide group; the ring structure is formed from the disulp[hide] form on oxidation of the cysteine residues*. The various oxyt[ocins] and vasopressins differ only in the nature of the amino aci[ds at] positions 3, 4 and 8. The molecular weight is just over 1000. [The] structure and biological activity of the naturally occurring [hor]mones are shown in the table on page 724. Arginine vasopr[essin] occurs in most mammals whereas lysine vasopressin is confine[d to] species of swine[5]. The aspartic acid residue in position 5 and [the] glycinamide residue in position 9 are essential for oxytocin activity, while the basic side chain at position 8 is essential for [anti]diuretic activity[6]. The activity varies with the size of the ring [and] is not dependent on the existence of the disulphide bridge: acti[vity] persists after replacement of the cysteine S of position 1 by a [...] group[7].

Units, methods of assay

Synthetic preparations of both these human posterior lobe [hor]mones are available. 1 International Unit (IU) of oxytocic, v[aso]pressor and antidiuretic activity is contained in 0.5 mg of the International Standard (see page 762).

Various biological methods are available for the assay of posterior lobe hormones[8], some of which are given in the table [on] page 724. In interpreting the results it must be borne in mind t[hat] most tissues contain other pharmacologically active substan[ces] like histamine, serotonin, acetylcholine and bradykinin, to wh[ich] the methods of bioassay used for the hormones also respond.

Assay of oxytocic activity is usually carried out by measur[ing] the contractions produced by the preparation in the isolated ute[rus] of rats pretreated with oestrogens (rat uterus test), that of va[so]pressor activity by determining the rise of blood pressure cau[sed] by the preparation in the carotid artery of rats. Radioimmunolo[gi]cal techniques may soon be available[9].

Biosynthesis, secretion, metabolism[10]

Oxytocin and vasopressin are formed in the hypothalamus a[nd] stored in the posterior lobe of the pituitary. The GOLGI appara[tus] of the hypothalamic neurones, the nucleus supraopticus and [nu]cleus paraventricularis produce a neurosecretory protein mater[ial] that is deposited as required in nerve endings in the posterior lo[be,] a process requiring its transport by the axoplasm of the sup[ra]opticohypophyseal tract[11]. Both oxytocin and vasopressin ha[ve] been isolated from this material. The neurosecretion can be de[m]onstrated under the optical microscope by suitable staining (f[or] example GOMORI's); under the electron microscope it appears [as] dense granules 0.1–0.3 μm in diameter. The accumulation of the granules accounts for the specific staining of the nerve endings a[nd] for HERRING's bodies. When the pituitary stalk is cut the neur[o]secretion accumulates in the proximal ends of the axons. Physi[o]logical stimuli depleting neurohypophyseal activity also deple[te] stainable neurosecretion in the hypothalamus and posterior pit[uitary].

* If the cysteine residues linked by the disulphide bridge are reckoned [as] a single amino acid (cystine) oxytocin and vasopressin are octapeptides.

(For references see page 725)

individual secretory neurone secreting only one hormone and
ecies differences in the proportion of vasopressin-producing
xytocin-producing neurones in the nuclei supraopticus and
ventricularis[14].

he neurosecretory cells with thickened nerve endings contain
secretion attach themselves to the walls of the posterior lobe
llaries and there give up their hormones; this process is cal-
n-dependent[15].

he posterior lobe was formerly thought always to release oxy-
in and vasopressin together into the circulating blood, regard-
of the nature of the stimulus Several examples of independent
ase have, however, been described[17, 18 34]. Thus vasopressin,
not oxytocin, is secreted following haemorrhage and on stim-
tion of the sinus nerve by carotid occlusion, while oxytocin, but

ssayed in these media by the methods at present available The
lasma vasopressin level at a normal state of hydration has been
timated at 1-5 mIU/l (1 mIU = ca 1 × 10⁻¹² mol) (for measured
alues see the table below)

e hormones are found only in the plasma and are not bound to
the erythrocytes[19] It is uncertain to what extent the hormones are
bound to plasma proteins; under physiological conditions they are
probably mainly present in the free form[19]

Vasopressin content of the peripheral plasma (mIU/l)

Normally hydrated		Dehydrated		Reference
Mean	Range	Mean	Range	
1 3	1 0-2 7	6 5	3 4-9 0	36
0 0	–	4 6	2.5-10 0	37
–	0 2-0 4	–	0 9-1 0	38

The hormones disappear rapidly from the
a result of
kidneys. Th
of oxytocin
pressin leve
urinary clea
5-32 mIU/l
down vaso
kidneys bu
glands, the myometrium in pregnancy and the placenta. In preg-
nant women the enzyme oxytocinase appears in the serum and is
capable of breaking down both
A syndrome of
has been recogni
Its main features
hypertonic urine
mone has been

Biological activity

The posterior pituitary hormones act on the epithelial mem-
branes – such as the distal renal tubules in mammals and the ski
and bladder in tailless amphibians – by increasing their permea-

polarization following electrical or chemical stimulation[2]. At the biomolecular level the change in permeability is possibly due to enhanced synthesis of cyclic adenosine 3′,5′-phosphate[24] Vasopressin-like polypeptides (see page 725) and possibly also vaso-

severe injury to the hypothalamus or destruction of the neurosecretory cells

The effect of oxytocin on milk ejection is so powerful that injection of as little as 0 01 IU has an action on the mammary glands of lactating women[27]. Release of oxytocin from the posterior pituitary is initiated by the suckling stimulus, but there may be considerable psychic modifications of this reflex activity

The physiological function of *vasopressin* consists of a role in the production of hypertonic urine[28] When the hormone is absent from the blood the aqueous permeability of the distal convolution and collecting tubule of the nephron is lowered In water diuresis the hypotonic fluid flowing out of the ascending part of the loop of HENLE into the distal convolution remains hypotonic up to the mouth of the collecting tubule Absorption of water in these parts of the tubule almost ceases since the reduced aqueous permeability means that there is no osmotic transfer of water to the isotonic interstice of the cortex and hypertonic interstice of the medulla In the presence of vasopressin, on the other hand, the aqueous

to be pumped against an osmotic gradient, and active transport of water in this way has so far never been observed, in the production of both hyper- and hypotonic urine only solute particles (mainly sodium ions) are actively transported, the subsequent osmotic transfer of water being prevented by the impermeability of the

The release of vasopressin from the posterior pituitary is thought to be regulated by the total osmotic concentration of electrolytes in the extracellular fluid Thus when loss of water by the body causes the osmotic concentration to rise, more antidiuretic hormone is released, more water is reabsorbed in the kidneys, and a more concentrated urine is produced Excessive intake of water has the opposite effect and a very dilute urine is produced (water diuresis) However, the osmotic concentration undergoes only slight

Structure and biological activity of naturally occurring neuropituitary hormones[33]

	Structure	Oxytocin-like activity (IU/mg)			Vasopressin-like activity (IU/mg)		Occurrence
		Uterus (rat, *in vitro*)	Blood pressure (chicken)	Mammary glands (rabbit)	Blood pressure (rat)	Anti-diuresis (rat)	
Arginine vasopressin (Arg^8-vasopressin)	Cys·Tyr·Phe·Glu(NH_2)·Asp(NH_2)·Cys·Pro·Arg·Gly·NH_2 1 2 3 4 5 6 7 8 9	16	60	70	400	400	Man, many mammals
Lysine vasopressin (Lys^8-vasopressin)	Cys·Tyr·Phe·Glu(NH_2)·Asp(NH_2)·Cys·Pro·Lys·Gly·NH_2 1 2 3 4 5 6 7 8 9	5	40	45	280	250	Pig, hippopotamus
Oxytocin (Ile^3–Leu^8-vasopressin)	Cys·Tyr·Ile·Glu(NH_2)·Asp(NH_2)·Cys·Pro·Leu·Gly·NH_2 1 2 3 4 5 6 7 8 9	450	450	450	5	5	Man, many vertebrates
Arginine vasotocin (Ile^3–Arg^8-vasopressin)	Cys·Tyr·Ile·Glu(NH_2)·Asp(NH_2)·Cys·Pro·Arg·Gly·NH_2 1 2 3 4 5 6 7 8 9	155	285	210	245	250	Birds, reptiles, fish
Isotocin (Ser^4–Ile^8-oxytocin, Ile^3–Ser^4–Ile^8-vasopressin)	Cys·Tyr·Ile·Ser·Asp(NH_2)·Cys·Pro·Ile·Gly·NH_2 1 2 3 4 5 6 7 8 9	150	320	300	0.06	0.18	Many bony fish
Mesotocin (Ile^3–Ile^8-vasopressin)	Cys·Tyr·Ile·Glu(NH_2)·Asp(NH_2)·Cys·Pro·Ile·Gly·NH_2 1 2 3 4 5 6 7 8 9	289	498	328	6	1.1	Frog, bichir
Glumitocin (Ile^3–Ser^4–Glu^8-vasopressin)	Cys·Tyr·Ile·Ser·Asp(NH_2)·Cys·Pro·Glu(NH_2)·Gly·NH_2 1 2 3 4 5 6 7 8 9	8					Many elasmobranch fish

the median eminence of the pituitary stalk. Factors identified in the hypothalamus (or neuropituitary) of various animal species are listed in the table below.

Hypothalamic pituitary-regulating factors

	Abbreviation	Reference
Corticotropin-releasing factors	α_1-CRF	5
	α_2-CRF	6
	β-CRF	6, 7
Melanocyte-stimulating-hormone releasing factor	MRF (MSH-RF)	8
Melanocyte-stimulating-hormone inhibiting factor.	MIF (MSH-IF)	9
Follicle-stimulating-hormone releasing factor	FRF (FSH-RF)	10
Luteinizing-hormone releasing factor.	LRF (LH-RF)	11
Prolactin-releasing factor.	PRF (pigeons)	12
Prolactin-inhibiting factor	PIF (mammals)	13
Growth-hormone releasing factor . .	GRF (GH-RF)	14
Thyroid-stimulating-hormone releasing factor . . .	TRF (TSH-RF)	15

so that this hormone does not appear to be a simple polypeptide

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[3] SCHALLY et al

Thyroid hormones[1–3] (for references see page 728)

Chemistry

The normal human thyroid gland contains about 8 mg of iodine[4] Over 99% of this iodine is present in the organic form as the iodinated amino acids monoiodotyrosine, di-iodotyrosine, triiodothyronine and thyroxine

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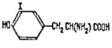
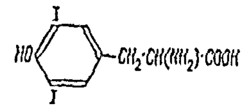
L-3-Monoiodotyrosine 

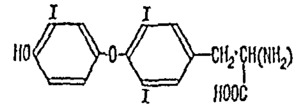
Thyroid Hormones

(For references see page 728)

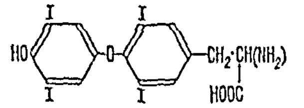
L-3,5-Di-iodotyrosine (L-iodogorgoic acid)



L-3,5,3'-Tri-iodothyronine



L-Thyroxine



In the thyroid by far the greater part of these iodinated amino acids is bound to high-molecular proteins, the most important of which is thyroglobulin, a glycoprotein with a molecular weight of 660000 and a sedimentation constant of 19 S[5]. Each molecule of thyroglobulin contains roughly 110 tyrosine residues and 26 atoms of iodine[6]; it has also been estimated that each molecule includes 7 monoiodotyrosine residues, 6 di-iodotyrosine residues and 1 thyroxine residue, while every third molecule contains a tri-iodothyronine residue. The proportions of the individual iodinated amino acids present in thyroglobulin depend on the iodine uptake; thus iodine deficiency results in an increase in the proportion of mono-iodotyrosine and tri-iodothyronine.

Biosynthesis, secretion, metabolism

The iodine ingested with food is transported by the blood in the form of iodide, which is then taken up in large amounts by the thyroid. Iodide concentration also occurs in other organs, su the salivary glands, gastric mucosa, skin, mammary glands placenta, but only in the thyroid is this process subject to ph logical regulation. Iodide concentration by the thyroid is st lated by thyrotropin, inhibited by hypophysectomy. The iodi oxidized to iodine or iodinium ions in the epithelial cells o thyroid follicles under the action of the enzyme peroxidase. still not clear whether iodination of the amino acids and coup of the tyrosines to thyronines takes place in the cells of the thy at the cell-colloid boundary, or even in the colloid itself. known, however, that there are variations in the degree of iod tion as well as in the structure of the thyroglobulin in the foll lar lumina.

The thyroid hormones – thyroxine and tri-iodothyronine – discharged into the blood only after enzymatic breakdown of thyroglobulin, a process stimulated by thyrotropin. Thyroglob is also present in the lymph of the thyroid, but the physiolog significance of the transport of this substance by the lymph system is unknown[7]. The mono- and di-iodotyrosines arising fr the breakdown of thyroglobulin are deiodinated in the thyroid, iodine so liberated being again available for the synthesis of thyr hormones.

Over 90% of the circulating thyroid hormones consists of t roxine. Mono- and di-iodotyrosines do not appear to be norm present in the blood[8], although there are reports to the contrar Most of the thyroxine in the serum is bound physicochemically certain carrier proteins[10], the tri-iodothyronine to a much smal extent (for normal values of the protein-bound iodine see page 5 and the lower table below). Thyroxine is mainly linked to 'thyrc ine-binding globulin', lying electrophoretically between the α_1- a α_2-globulins, and 'thyroxine-binding prealbumin', though some present in the albumin fraction. Dialysis against a protein-free buf shows that the proportion of the total thyroxine present in the fr state is about 0.05%; the proportion of free tri-iodothyronine some 10 times greater[11]. Very probably only the free thyroid ho

*Metabolic data for iodide**[3]

Age (years)	Plasma iodide concentration (µg/l)				Iodide clearance by thyroid (ml/min)				Absolute iodine uptake of thyroid (µg/h)				Renal iodide clearance (ml/min)			
	Men		Women		Men		Women		Men		Women		Men		Women	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
0–19 . .	1.4	–	0.8	0.6–1.0	23.0	–	36.2	31.5–40.9	2.0	–	1.6	1.4–1.9	27.0	–	31.5	30.2–32.7
20–39 .	2.3	0.8–3.4	1.6	0.4–2.7	27.5	9.7–57.8	26.4	19.7–38.2	3.2	1.9–8.2	2.2	0.9–3.4	40.6	25.9–61.8	25.0	15.7–41.3
40–59 .	1.7	0.4–3.6	1.6	0.8–2.6	21.8	2.9–38.5	15.6	5.7–37.6	2.5	0.1–6.7	1.3	0.6–2.2	38.8	17.9–53.8	28.4	19.0–37.4
> 60 . .	1.7	0.4–3.5	2.5	1.4–5.7	25.3	13.8–36.0	18.3	5.4–38.6	2.0	0.8–2.9	2.1	0.5–3.1	27.2	21.0–30.8	19.3	11.7–38.5

* Wide deviations from these values may occur in subjects with a high iodine intake.

Thyroid hormones in blood[35]

Age (years)	Endogenous thyroxine distribution (%)						Thyroxine-binding capacity (µg thyroxine/l serum)				Protein-bound iodine (µg/l serum)		Free thyroxine			
	Thyroxine-binding globulin		Thyroxine-binding prealbumin		Albumin		Thyroxine-binding globulin		Thyroxine-binding prealbumin				(ng/l serum)		(% of total serum thyroxine)	
	Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	Mean	s	Mean	s
2–12 . .	55.0	7.0	26.8	5.5	18.2	3.7	27.3	3.6	72	26	61	7	47.0	7.4	0.050	0.007
16–20 . .	43.4	7.2	39.6	6.5	17.0	3.9	–	–	–	–	52	7	36.0	7.7	0.050	0.015
21–30 . .	40.2	4.0	43.1	5.9	16.6	3.3	–	–	–	–	52	11	44.6	14.1	0.057	0.015
31–40 . .	39.5	5.7	44.6	5.8	15.8	1.5	21.5	3.6	183	26	52	7	42.7	9.1	0.055	0.011
41–50 . .	41.7	7.1	42.7	7.9	15.7	2.5	–	–	–	–	53	9	46.0	11.4	0.057	0.008
51–60 . .	44.6	6.3	37.8	6.4	17.7	4.3	–	–	–	–	48	5	35.1	3.8	0.050	0.004
61–70 . .	47.8	9.7	36.5	8.9	15.5	3.1	25.3	5.8	128	60	54	8	47.5	12.3	0.058	0.014
> 70 . . .	50.8	4.7	29.7	5.8	19.5	7.3	–	–	–	–	51	12	42.0	13.4	0.054	0.008

s the important property of stimulating the maturation of
rebral cortex in the critical phase of development[25]

rative potencies of the thyroid hormones and related compounds[12, 36]

	Species	Physiological test		
		Calorigenic action	Growth and differentiation	Thyrotropin depression
hyroxine	All	100	100	100
hyroxine	Rat	5–8	–	–
	Man	8–12	–	–
,3'-Tri-iodo-L-thyronine	Rat	150–350	500	–
	Man	100–250	–	280–540
,3'-Tri-iodo-D-thyronine	Rat	10–15	–	14
-Di-iodo-L-thyronine	Rat	0–5	–	–
odo-L-thyronine	Rat	0–3	–	–
-Di iodo-3'-methyl-DL-thyronine	Rat	150	–	–

he action of the thyroid hormones is marked by a so-called
nt period', thus in man the basal metabolic rate only begins to
2 days after their administration
he biomolecular effects of the thyroid hormones have also been
lied[28] These include modification of the activity of many en-
es, uncoupling of oxidative phosphorylation in the mitochon-
dria, alteration of the permeability of the mitochondrial membrane, and stimulation of protein synthesis. Some workers regard the last-named action as a primary effect of the hormones to which the calorigenic action is secondary.

The effects of the thyroid hormones and related compounds are closely linked with their chemical structure[27]. In the iodinated thyronines the steric configuration appears to be mainly respon-

enterally tri iodothyronine is twice as active as thyroxine, when given orally four times as active. While thyroxine and tri-iodothyronine have qualitatively the same effects the calorigenic action of the latter is considerably quicker but not so long-lasting

Evaluation of thyroid function[3, 26]

Little can be deduced as to the functional state of the thyroid from its size and shape alone Except in hyperthyroidism, hyperplasia of the gland merely reflects its increased stimulation by thyrotropin due to increased secretion of this hormone triggered by a reduction in the concentration of thyroxine in the blood (feedback mechanism). This reduction is in turn the result of a substrate

cept in the presence of extreme iodine deficiency or severely impaired synthesis A severe functional disturbance may, however, be unaccompanied by goitre.

The functional state of the thyroid is best assessed by studying the individual phases of the iodine cycle · iodine uptake, hormone synthesis, hormone release, hormone transport, peripheral hormone uptake, iodine excretion There is an equilibrium between these various phases that is also maintained in both hypo- and hyperthyroidism In hyperfunctioning of the thyroid the iodine uptake of the gland is increased along with the rate of hormone synthesis, and the circulating free thyroid hormones are more quickly taken up by the tissues and broken down In hypofunctioning of the gland all these phases are slowed down The apparent thyroid hyperfunctioning of pregnancy is the result of increased renal iodide clearance with a compensating increase in thyroid function[37].

Iodine uptake phase Measurement of the accumulation of a radioactive iodine isotope

values[35].

Hormone uptake phase Measurement of the half-life of intravenously injected radioactive thyroxine

Thyroid activity can also be evaluated indirectly from the activity of the thyroid hormones, for example by measuring the BMR (see page 539), the oxygen consumption of the leucocytes, or the time of the Achilles tendon reflex[34] (slowed in thyroxine deficiency, accelerated in thyroxine excess).

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Parathyroid hormone[1-3]

(parathormone)

Chemistry

Purified bovine parathyroid hormone has a molecular weight of 8500 and is a single-chain polypeptide with no covalent intra-chain cross linkage[4]. A highly purified preparation with a biological activity of 2500–3000 USP units per milligramme can be obtained by gel filtration. The empirical amino-acid composition of bovine parathyroid hormone is Lys_9, His_4, Arg_5, Asp_8, Thr, Ser_4, Glu_{10}, Pro_5, Gly_4, Ala_7, Val_7, Met_2, Ile_3, Leu_8, Tyr, Phe_2, Trp. Parathyroid hormone is inactivated irreversibly by pepsin, trypsin and chymotrypsin, reversibly by hydrogen peroxide.

Units, methods of assay[5]

1 USP Unit = 1/100 of the amount that when administered parenterally to dogs weighing 8–16 kg increases the serum calcium concentration by 1 mg/100 ml within 16–18 hours. The activity of preparations can be determined by making use of this action (serum calcium level[6] or by measuring their effect on the u phosphate excretion of parathyroidectomized rats[7]. The amo the hormone present in body fluids can be determined by me its immunological properties, using either the complement-fi test[8] or radioimmunological methods[9].

Biosynthesis, secretion, metabolism

Parathyroid hormone is formed in the chief cells, the light cells and possibly also the oxyphile cells of the parathyroid[1] tracytoplasmic droplets seen in Golgi's apparatus may repr an intracellular form of the hormone[11]. Discharge of the hor into the blood is regulated by the diminution in the concentr of ionized calcium in the blood flowing into the parathyro This does not apply in primary hyperparathyroidism, in whic parathyroid secretes the hormone independently of the bloo cium level. The hypothalamus and pituitary have no detec effect on the secretion of parathyroid hormone. A substanc munologically similar to parathyroid hormone is produced by s nonendocrine tumours[36].

Published data on the parathyroid hormone content of the b vary widely. Biological methods give values of 25 µg/l plasm more, radioimmunoassay values of 0.1 to 1.0 µg/l plasma. The p ma level is increased in adenoma of the parathyroid, some form carcinoma (pseudohyperparathyroidism) and chronic kidney dis (secondary hyperparathyroidism)[13]. The circulating hormone is idly broken down (half-life in rats 22 min[14]), probably in the liv Parathyroid hormone is excreted in the urine, the amount decr ing as the level of ionized calcium in the serum rises[15].

Biological activity

Parathyroid hormone maintains the concentration of ioni calcium in the extracellular fluid, a function in which vitamin (see page 461) and thyrocalcitonin (see page 718) are also involv The hormone has a direct action on bone[16], in which it cau breakdown of the bone substance reflected in an increase not o of the blood calcium but also of the urinary excretion of mu proteins[17], hydroxyproline[18] and pyrophosphate[19].

The other site of action of parathyroid hormone is the re tubules, where it promotes the excretion of inorganic phosphate 15–40 min after administration of the hormone the latter reache maximum lasting several hours, and the consequent fall in the ser phosphate level entails a rapid rise in the serum calcium level. M bilization of calcium takes place more slowly, however, with a m imum after 6 hours or more, since it is preceded by an increased f mation of osteoclasts[3]. There are also indications that the hormo maintains the blood calcium level by stimulating tubular reabso tion of calcium[21] and intestinal calcium absorption[22]. Parathyro hormone has also been observed to have an effect on lactation

The mode of action of parathyroid hormone has been exte sively investigated. The hormone could act on the skeleton by (releasing a collagenolytic factor from the bone cells[24], and (b) pr moting the formation of citrate and lactate and thus displacing t pH to the acid side, with a consequent increase in dissolution of t hydroxyapatite of bone[25]. The action of the hormone on bone, b not that on renal tubular function, requires the presence of vit min D[26,27]. At the molecular level parathyroid hormone increas the uptake of phosphate by the mitochondria and, in conjunctio with vitamin D, the mobilization of calcium[26,28]. The action o bone is inhibited by actinomycin D, so that this effect, unlike th on the renal tubules, probably has a genetic mechanism[11,29].

Evaluation of parathyroid function[30,31]

Hyperparathyroidism is often accompanied by a rise in seru calcium, increased urinary excretion of phosphate and calcium, an a fall in serum phosphate. The urinary phosphate excretion can b measured by the phosphate clearance[32], by the percentage tubul reabsorption of phosphate[33], or by the phosphate excretion in dex[34] (see also page 663). Parathyroid suppression tests have bee developed for distinguishing primary hyperparathyroidism fro other diseases accompanied by disturbance of calcium metabo lism[31,35]; these involve measurement of the effect of a calciu infusion on phosphate excretion.

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ʼhymus hormone

In adult healthy mice thymectomy has virtually no effect except ›r slight lymphopenia, whereas in newborn animals the operation ›sults in very severe disturbances all of which have their origin in state of immunological insufficiency[1]. Intraperitoneal reimplanta-on of the thymus in a diffusion capsule is followed by reversal of ıese changes to a very large extent. It has been concluded that the ıymus produces a humoral factor involved in the development of nmunological competence (competence-inducing factor), pos-bly by furthering the maturation or differentiation of immuno-›gically competent cells from their lymphoid precursors[2]. The ›rmation by the thymus of a humoral factor stimulating the pro-feration of lymphatic tissue (lymphocyte-stimulating factor) had een postulated earlier[3]. Such a factor is possibly produced by the ıedullary epithelioid cells of the thymus in the form of an acid ıucopolysaccharide containing sulphate[4]. A lymphopoietic factor :tive in vitro has been isolated from calf thymus and identified as heat-stable protein containing carbohydrate[5]. The immunologi-ıl reactivity of thymectomized mice can be restored by adminis-:ring an extract of calf thymus[6]. Several humoral factors may ›ntribute to the functioning of the thymus[7].

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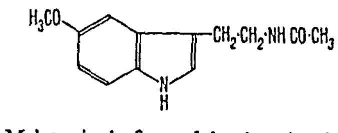
ormones of the pineal gland

In man the pineal organ is a conical, midline structure about mm long located on the dorsal posterior edge of the epithalamus. arises embryologically as an evagination of the neuroectoderm ' the dorsal diencephalon. It is composed of epithelioid paren-ıymal cells, and usually contains calcareous deposits in sexually ature individuals. Phylogenetically it is the remnant of midline ›rsal light receptors.

Possible pineal hormones. Melatonin (melanocyte-contracting principle, skin-lightening factor) is produced in the vertebrate pineal[1]. :rotonin, as well as its metabolites such as 5-hydroxyindoleacetic :id, occur in the mammalian pineal in high concentrations. Nor-lrenaline and histamine are found in pineal extracts[2]. Anoestrin, ı inhibitor of oestrus, and antigonadotrophic factors have also :en alleged to be present in the pineal; they may be identical with elatonin[2]. Glomerulotropin (adrenoglomerulotropin), an accel-ator of aldosterone secretion, has been postulated as a pineal hor-one[3]; it is reported to be a carboline derivative[4].

Melatonin (*N*-acetyl-5-methoxytryptamine)



Melatonin is formed in the pineal gland by methylation of *I* acetyl-5-hydroxytryptamine[1], the reaction being catalysed by h droxyindole *O*-methyltransferase, a specific enzyme apparently o curring only in the mammalian pineal[5]. The circulating melaton is rapidly taken up by the tissues, where it is converted mainly in 6-hydroxymelatonin; this substance is excreted in the urine main as the sulphate and to a smaller extent as the glucuronate[6].

In rats, the weight, morphology and chemical composition c the pineal gland can be altered by exposing the animals for lon periods to continuous light or darkness. Thus light exposure cause the parenchymal cells to contract[7], while dark exposure increase the activity of the enzyme hydroxyindole *O*-methyltransferase an therefore the rate of melatonin synthesis[8]. The serotonin, mela tonin and hydroxyindole *O*-methyltransferase contents of th pineal gland are subject to a day-and-night rhythm[8,9] as a result o sympathetic nervous regulation by the amount of light entering the eyes.

In amphibia, melatonin acts as an antagonist to MSH by causing the melanophores to contract (see page 722). In rats, melatonin has been reported to reduce the weight of the ovaries and to inhibit oestrus and sexual development[2,10]; it also inhibits the increased frequency of oestrus observed in pinealectomized rats[11]. In human males, parenchymal-cell pineal tumours are associated with sexual retardation, whereas nonparenchymous tumours which destroy the pineal are associated with sexual precocity[12].

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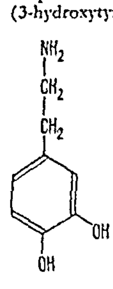
Catecholamines[1-4] (for references see page 734)

Chemistry

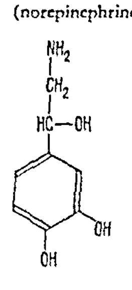
The catecholamines are phenylethylamine derivatives in which the benzene ring is *ortho*dihydroxy-substituted, as in catechol. The most important members of this group are dopamine, noradrenaline and adrenaline. The catecholamines occur not only in the vertebrates but also in insects, where *N*-acetyldopamine also plays an important role[5]. The naturally occurring catecholamines are laevorotatory, the dextrorotatory forms being almost devoid of biological activity.

All the catecholamines have very similar chemical properties. Adrenaline and noradrenaline are oxidized spontaneously in alka-

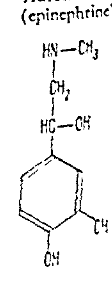
Dopamine (3-hydroxytyramine)



Noradrenaline (norepinephrine)



Adrenaline (epinephrine)



(For references see page 734)

ds of assay[6,7]

catecholamines can be determined by a variety of chemical

r clinical purposes the chemical methods of assay are prefer-
adrenaline and noradrenaline are best determined by the trihy-
ndole method (as modified for instance by CROUT[8], SOURKES

tivity of methods of catecholamine assay[44]

Method	Sensitivity (ng) Adrenaline	Noradrenaline
logical		
Blood pressure, cats	200	100
Blood pressure, rats	50	3
Blood pressure, rats (SHIPLEY and TILDEN)	7	5
Uterus, rat (2 ml)	0 1	15
Ear, rabbit (perfusion)	0 5	1
Ear, rabbit (ARMIN and GRANT)	0 002	–
Intestinal muscle, rabbit (10 ml)	40	40
Intestinal muscle, chicken (2 ml)	2	50
hemical		
Colorimetrically as adrenochrome	10000	10000
Reduction of arsenomolybdate	50	800
Ethylenediamine method	6	6
Trihydroxyindole method	5	5

synthesis, secretion, metabolism, excretion

The enzymes necessary for the biosynthesis of the catechol-
ines from tyrosine are found in the cells of the adrenal medulla
the sympathetic neurones The steps in this synthesis are L-
osine → L-dopa → L-dopamine → L-noradrenaline → L-adren-
e, and are

ased nerve activity[46] and rises when nerve activity is inter-
pted[47] Noradrenaline synthesis in the neurones is possibly reg-
ted by a negative feedback mechanism[48] In the adrenal me-

dulla a small amount of the adrenaline formed is further converted into N-methyladrenaline[13]

nals of all species, its proportion in the total catecholamines does not exceed 2%[3].

the peripheral tissues at a concentration of about one-tenth of that of noradrenaline[3] Noradrenaline occurs in the brain in various species at a concentration of 0 2–0 5 μg/g, the highest values being

Tumours of chromaffin tissue sometimes contain large amounts of catecholamines, and values of up to 8 4 mg/g for noradrenaline and 2 3 mg/g for adrenaline have been recorded[20]

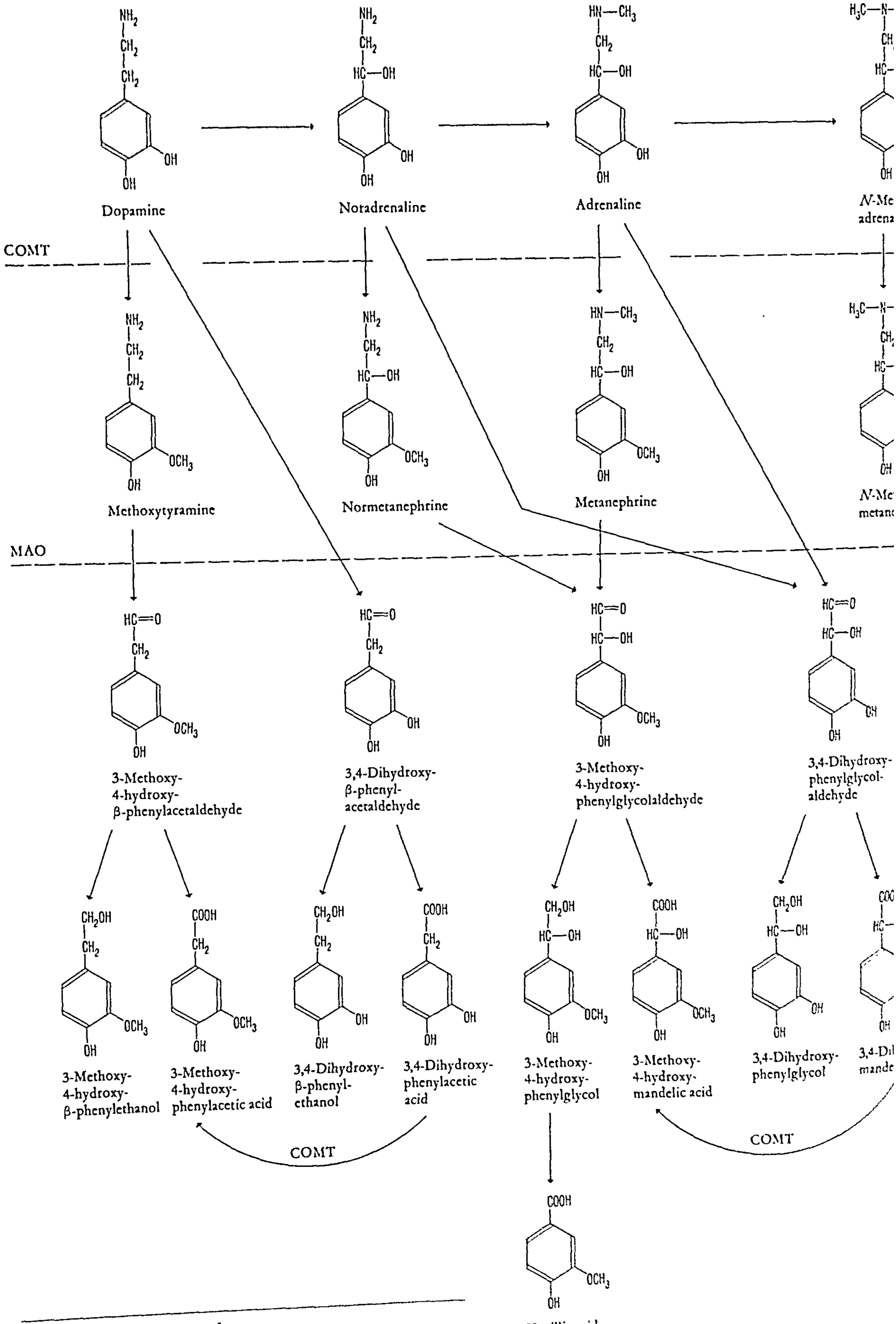
Secretion of catecholamines. Release of catecholamines from the adrenal medulla into the blood is actuated by nervous stimuli via the splanchnic nerves Secretion of the hormones is stimulated by stress and by administration of histamine and other drugs, it is also increased in insulin-induced hypoglycaemia In general the medulla secretes the catecholamines in proportions that remain constant in

tents of the chromaffin granules – catecholamines, ATP and pro-

The plasma adrenaline level rises on changing from the recumbent to the e posture and during phy al exercise, the adrenaline level during sulin hypoglycaemia (for b iography see LORAINE and BELL[7]). In patients with catecholamine producing tumours, noradrenaline levels of over 100 times the normal have been observed[25]

From the blood the catechol

Metabolism of catecholamines



COMT Catechol *O*-methyltransferase
MAO Monoamine oxidase

s levels of adrenaline and noradrenaline (μg/l)

	Adrenaline		Noradrenaline		Reference
	Mean	*s*	Mean	*s*	
ydroxyindole method					
.dults	0.06	0.05	0.30	0.07	52
Ien.....	0.07	0.01	0.35	0.01	53
Vomen	0.06	0.01	0.35	0.01	53
iylenediamine method					
Adults	0.22	0.27	0.58	0.66	10
Newborn....... ..	0.35	0.64	2.39	2.69	54
Premature	0.86	1.21	3.24	2.03	54

ce adrenalectomy reduces the excretion of adrenaline but not it of noradrenaline[28]. Administration of ³H-labelled adrenaline

techolamine excretion in nocturnal urine (μg/h)[45]

	Free amines		Total amines	
	Mean	Range	Mean	Range
Adrenaline	0.04	< 1.29	0.06	< 2.35
Noradrenaline	2.36	<11.0	4.69	<21.6
Dopamine	8.22	<23.3	27.2	10.2–56.8
Metanephrine	1.25	< 6.80	3.65	<13.3
Normetanephrine	8.55	<17.8	17.5	4.82–58.0

droxyphenylglycol sulphate.

Normal values for the excretion of catecholamines and their most important metabolites are summarized in the tables on this page. The excretory levels of these compounds are dependent on body

by persons with tumours of chromaffin tissue, considerable amounts of dopa, dopamine and their metabolite homovanillic acid by those with neuroblastomas (for further details see the literature[20,21]).

Biological activity

In the animal organism the catecholamines have two important functions, the main physiological function of those secreted by the adrenal medulla being concerned with metabolism, while those released by the adrenergic synapses of the sympathetic nervous system act as transmitters of nervous stimuli.

Metabolic effects. Adrenaline increases oxygen consumption in

cycle). In the liver, stimulation of glycogenolysis by the catecholamines leads to an increase of glucose output and a short-lived rise

Excretion of catecholamines and 3 methoxy-4-hydroxymandelic acid by children and adults

Age (years)	Number	Urinary volume (ml/24 h)	Adrenaline (μg/24 h)		Noradrenaline (μg/24 h)		Dopamine (μg/24 h)		3 Methoxy-4-hydroxy-mandelic acid (mg/24 h)		Reference
			Mean	*s*	Mean	*s*	Mean	*s*	Mean	*s*	
0–1	19	370	1.3	1.2	10.6	3.4	60.9	24.3	0.5	0.31	29
1–5	15	492	3.2	2.7	18.8	7.0	124.1	40.7	1.3	0.44	29
6–15	13	845	4.8	2.4	37.4	16.6	169.3	72.6	2.37	0.70	29
>15	13	1552	7.1	3.3	50.7	15.7	249.1	74.9	3.19	0.67	29
0–10	46	380	9.2	8.6	19	13	–	–	1.0	0.9	67
10–30	28	1010	22	14	52	31	–	–	3.6	1.9	67
30–50	33	1280	26	22	66	34	–	–	4.2	1.7	67
50–70	42	1500	28	21	60	34	–	–	4.1	1.5	67
70–99	8	1010	19	12	43	27	–	–	3.2	1.3	67

logical conditions and produces a rapid breakdown of glycogen to glucose 1-phosphate. Catecholamines appear to activate phosphorylase by a similar mechanism in all tissues. The lipolytic action of adrenaline and noradrenaline appears also to be mediated by cyclic AMP[37], but different forms of a triglyceride lipase have not yet been isolated.

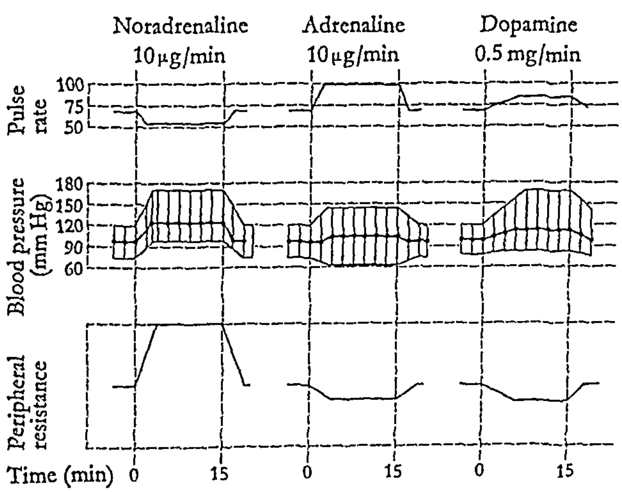
Pharmacological effects. Experimental studies have led to the idea of at least two kinds of adrenaline receptors, α and β[38]; α receptors mediate largely motor effects, β receptors largely the remaining effects. Noradrenaline acts on α receptors, isoprenaline on β receptors, adrenaline on both; adrenaline antagonists act primarily on α receptors. This is an oversimplified picture, and exceptions exist which have led to a further, though somewhat unprofitable, multiplication of postulated receptors.

Effects on blood circulation (see the figure below). In man, continuous intravenous infusion of catecholamines (0.1–0.3 μg/min/kg body weight) can have the following effects[40]: *Noradrenaline.* Prompt increase in the mean blood pressure of systolic and diastolic origin *due to an increase in the peripheral resistance (vasoconstriction).* Cardiac output unchanged or slightly diminished. *Adrenaline.* Increase in the mean blood pressure due to a fall in the blood pressure in the peripheral circulation (vasodilatation) being overcompensated by an increase in the beat volume and beat frequency. The circulatory effects of adrenaline and noradrenaline are mutually compensatory when the hormones are given at physiological dosage (intravenously up to 0.3 μg/min/kg body weight).

The continuous intravenous infusion of *dopamine* at dosages in the range 5.3–11.6 μg/min/kg body weight may result in an increase in the systolic and mean blood pressures and cardiac output and in a lowering of peripheral resistance[41].

Renal blood flow is diminished by adrenaline[42], large doses of which reduce the glomerular filtration rate. Adrenaline has little effect on the cerebral blood vessels.

Cardiovascular effects of intravenous infusion of noradrenaline, adrenaline and dopamine[39]



Catecholamines in the central nervous system. Impulses arriving at the efferent ends of the sympathetic nerves cause the release of small amounts of noradrenaline which stimulate or inhibit cellular activity in the target organ (see above). Noradrenaline[27] and dopamine[19] may exercise a similar function in the central nervous system. It has been suggested that in some kinds of depression, particularly the retarded type, there is a noradrenaline deficit at specific receptor sites in certain areas of the central nervous system; conversely, in manic states there would be an excess of noradrenaline in these areas[30].

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Insulin[1,2] (for references see page 737)

Chemistry

Up to 1966 the structure of insulins from 20 different animal species had been largely or wholly elucidated[3]. In almost all species the shorter A chain contains 21 amino-acid residues and has an N-terminal glycine residue, at least four free amino groups and an internal disulphide bridge between the cysteine residues at positions 6 and 11. Variations in the amino-acid sequence are mostly in positions 8, 9 and 10. The longer B chain is made up of 28–30 amino-acid residues and contains two or three free amino groups and, in most species, an N-terminal phenylalanine residue. Variations in the amino-acid sequence in this chain are mostly in positions 3, 29

(For references see page 737)

...o-acid sequence of beef insulin

/al Asp(NH₂) Glu(NH₂) His Leu Cys Gly Ser His Leu Val Glu Ala Leu Tyr Leu Val Cys Gly Glu Arg Gly Phe Phe Tyr Thr Pro Lys Ala
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 20 21 22 23 24 25 26 27 28 29 30

:le Val Glu Glu(NH₂) Cys Cys Ala Ser Val Cys Ser Leu Tyr Glu(NH₂) Leu Glu Asp(NH₂) Tyr Cys Asp(NH₂)
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

30. Of the 51 amino-acid positions in the insulin molecule, :e known to show variations. Human insulin differs from toad- insulin for instance in 17 of these positions. At least two spe- – rats and toadfish – form two structurally different insulins in : pancreas, while identical insulins may be formed by different ies, for instance the dog, pig, fin whale and sperm whale.

...rences in the amino-acid sequences of various insulins

Species	A chain position			B chain position
	8	9	10	30
Ox	Ala	Ser	Val	Ala
Pig	Thr	Ser	Ile	Ala
Sheep ...	Ala	Gly	Val	Ala
Horse	Thr	Gly	Val	Ala
Whale . .	Thr	Ser	Ile	Ala
Man	Thr	Ser	Ile	Thr

l undergoes aggregation to form polymers of at least two mol- iles (insulin dimer). Whether this occurs in complex solutions : blood is not known. Insulin readily forms complexes with zinc basic proteins such as histone and protamine. It crystallizes in ombi or prisms. Heating of insulin solutions at $pH < 3.5$ results in l to-end aggregation of insulin monomers to form the charac- istic insulin fibrils.

The insulins most commonly employed in the treatment of dia- tes in man are those of bovine and porcine origin. Pig insulin fers from human insulin in only one amino-acid residue (B ain, position 30), beef insulin in three (A chain, positions 8 and , B chain, position 30). This difference in amino-acid structure ay explain the greater antigenicity in man of beef insulin com- red to pig insulin. In the light of its amino-acid structure, homo- gous insulin would not be expected to induce the formation of rculating antibodies. It has recently been shown, however, that jection of insulin from beef pancreas into cattle[4] or of pig insulin to pigs[5] does in fact result in the formation of antibodies[6]. Fac- rs other than amino-acid sequence must therefore play a role in etermining antigenicity.

reparations of this kind with residual activity almost certainly ontain intact insulin.

The complete synthesis of sheep insulin was achieved by three roups of workers at about the same time[9], human insulin has lso been synthesized[10].

Proinsulin[11, 20] A minor component of pig insulin has been hown to be a single-chain protein of 84 amino acids, this is con- erted into insulin by proteolytic cleavage. It cross-reacts with in- ulin in immunoassay.

Synalbumin[12, 13] An insulin-antagonistic factor migrating elec- rophoretically with albumin has been described (synalbumin insu- n antagonist) the physicochemical properties of which suggest hat it consists of the B chain of the insulin molecule.

The presence of an artifactual insulin antagonist in albumin pre- parations has been reported[62].

Unit, methods of assay[14, 15]

viving tissues. The preparations commonly used are the rat dia- phragm, in which the index of insulin activity is glucose uptake or glycogen synthesis, and rat epididymal adipose tissue, in which the index can be glucose uptake, net gas exchange, oxidation of ^{14}C-labelled glucose to $^{14}CO_2$, or incorporation of the labelled glucose carbon into lipid or adipose tissue glycogen. These methods of

Biosynthesis, secretion, metabolism

1–4 IU/g[22], the total amount being 100–400 IU with a mean of 250 IU (10 mg). From radioimmunological assays of plasma insu- lin the daily production of the pancreas has been estimated to be about 50 IU[23], this corresponds to the daily average replacement dose in patients in whom endogenous production is completely suppressed.

Insulin secretion is stimulated or inhibited by a large number of factors[24–28] (see the table on page 736).

Stimulation of insulin secretion ...

... of insulin secretion is proportional to the amount of glucose flowing through the pancreas[2], though it is probably not the glucose itself that has the stimulating action but a metabolite from the pentose-phosphate cycle[28]. In man, the insulin level in the peripheral venous blood begins to rise within a few minutes of starting a glucose infusion[29].

The form in which insulin exists in the plasma is not known with certainty ...

Factors affecting insulin secretion[24–26]

	In vivo	In vitro
Factors stimulating secretion		
Glucose	+	+
Fructose	+	+
Mannose	+	+
Ribose	+	+
Xylitol	+	+
Ribitol		+
Leucine	+	+
Arginine	+	+
Acetoacetate	+	±
Glucagon	+	+
Growth hormone	+	±
Lactogenic hormone of the placenta	+	
ACTH	+	+
Glucocorticosteroids	+	±
Thyroxine	+	±
Pancreozymin	+	
Secretin	+	+
Insulin antibodies	+	+
Calcium		+
Magnesium		±
Potassium	+	+
Adenosine triphosphate		+
Adenosine cyclic monophosphate		+
Sulphonylureas	+	+
Vagus stimulation	+	
Factors inhibiting secretion		
2-Deoxyglucose	+	+
Glucosamine		+
Mannoheptulose	+	+
Adrenaline	+	+
Noradrenaline	+	
Insulin	+	
Phenethylbiguanides	+	
Diazoxides	+	+
Starvation	+	
Hypoxia		+
Vagotomy	+	

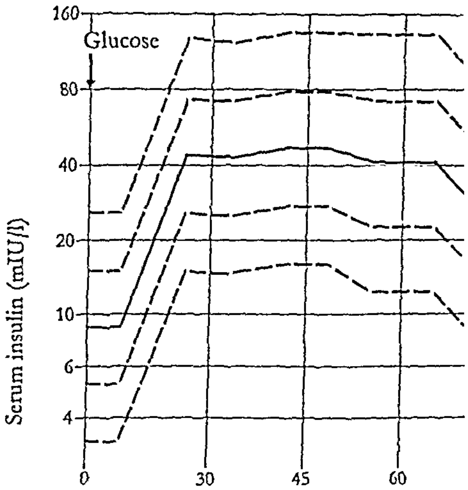
When serum is filtrated on Sephadex G-75, two protein peaks with a protein-free interval are obtained. Insulin-like activity is highest in the first protein fraction; insulin measured by immunoassay is highest in the 'protein-free' interval. This is also the area where labelled crystalline insulin is recovered[31]. When Sephadex G-50 is used for filtration, insulin appears in two peaks, designated 'big' and 'little' insulin, the first of which may be identical with proinsulin[20].

Different methods of assay measure different amounts of insulin and/or insulin activity in the serum. The following mean values have been found in the morning in the serum of persons who have fasted for 12 hours previously: 20 mIU/l by the radioimmunological technique (see the table on this page), 100 mIU/l by the rat diaphragm method[15] and 350 mIU/l by the rat adipose tissue method[31]. The insulin activity of the serum not inhibitable by insulin antibodies has been measured at about 170 mIU/l[32]. Serum insulin levels during the glucose-loading test are shown in the figure on this page. In pregnant women there is a rise in the serum insulin level towards term[34,35], and under glucose loading the level rises to a greater extent than post partum[34]. In the serum of cord blood the insulin level is low[36]. Small amounts of insulin have been detected in spinal fluid[37].

Plasma insulin determined by immunoassay (mIU/l in

	Mean	Range
Adults	20	0–66
Adults	20	6–35
Adults	22	–
Newborn, 2–8 days	43	–

Serum insulin after an oral dose of 50 g glucose[33] (values from 45 subjects, logarithmic scale)



Only part of the insulin secreted by the pancre
general circulation, nearly a half of it being remov
and degraded. In man the half-life in the circulating
30 minutes, in animals rather less[2]. Insulin also p
tissues, the highest concentrations of labelled insuli
found in the kidneys, liver and muscle. Small amou
are found normally in the urine; immunoassay of n
has shown an average of 5 mIU/24 h[38,39]. Insuli
adults is about 0.4 ml/min[38,39]; in children it is p
body weight and amounts to about 0.2 mIU/kg/24 h
lin filtered in the glomeruli is almost completely re
broken down in the tubules, the daily turnover bei
at a serum level of 14 mIU/l[38]. Degradation of insul
– and probably also in the kidneys and other tissues
by a specific enzyme, protein disulphide reductase,
the disulphide bonds to free the A and B chains[41],
turn are attacked by proteolytic enzymes. During p
placenta is also involved in the breakdown of insuli

Biological activity

Insulin has a direct or indirect effect on practically a
metabolic processes of the body. The most obvious
those most thoroughly studied, are on the fatty tissues
and liver[45]. Various theories have been put forward t
mode of action, which may well vary from site to si
sulin-enzyme theory, (b) the insulin-transport theory,
lin-gene (transcription) theory and (d) the insulin-ribo
lation) theory. For further details see the literature[46]

The most important role of insulin is in the metab
fatty tissues, the principal site of the regulation of en
and mobilization. Insulin promotes storage of fat and
release. The hormone stimulates glucose uptake an
phosphate metabolism in the fatty tissues as well as p
the formation of glyceride glycerol, fatty-acid synthes
cose, transamination of glucose into amino acids, and
thesis; it inhibits the release of fatty acids by promotin
tion of α-glycerophosphate, with which they form trig

In *muscle*, insulin activates the transport system res
the entry of amino acids and other compounds into th
the cell, glucose is converted into glucose 6-phosphate
hexokinase and finally into glycogen by activation o
cose-glycogen glucosyltransferase. Activation of the
amino acids proceeds independently of that of glucose

glucagon content of the pancreas, whereas damage to the α-cells by cobalt chloride or other compounds causes a gradual diminution of glucagon activity. Glucagon can be isolated from those parts of the dog pancreas which contain α-cells but is not found in the uncinate process, where α-cells are lacking. Furthermore, in different species the amount of extractable glucagon in the pancreas correlates well with the relative abundance of α-cells in the organ. Histochemically, tryptophan, a component of glucagon but not of insulin, can be demonstrated in α-cells but not in β-cells[1]. More direct evidence in favour of the α-cell origin of glucagon has been obtained recently with specific immunofluorescence techniques[11].

Both the muscular and mucosal layers of dog and human upper gastrointestinal tract have been found to contain significant amounts of a glucagon-like substance in measurements made by the method of liver adenyl cyclase assay[10]. A glucagon-like substance was also detected in the gastrointestinal tract by radioimmunoassay[12]. This technique reveals a glucagon content in the human pancreas of 4.0–12.4 μg/g and a content of glucagon-like substance in the human colon of 0.006–0.01 μg/g; the glucagon-like immunoreactivity of the whole digestive tract probably does not amount to more than 25–50% of that of the pancreas. Glucagon has also been identified radioimmunochemically in acid alcohol extracts of an undifferentiated bronchogenic carcinoma[13]. There is no evidence to suggest that glucagon is related to hyperglycaemic substances isolated from skin, lymph glands, tongue and spleen.

Published data on the plasma glucagon level in fasting subjects vary from 0.1 μg/l to 5 μg/l; more recent publications indicate that it is below 0.3 μg/l[14]. The glucagon content of the blood increases in starvation, insulin-induced hypoglycaemia, and phlorizin diabetes; administration of glucose to phlorizin-treated animals or persons with hypoglycaemia causes the blood glucagon level to fall[8,15]. Paradoxically, oral glucose loading also causes a rapid rise in the blood glucagon level, an effect that occurs to only a small extent when glucose is given intravenously[16]. This glucagon-like immunoreactivity probably arises from the gut[35]. In the blood, glucagon does not appear to be bound to plasma proteins[17].

Glucagon is degraded by the kidneys, liver and other organs and to some extent in the blood. Following injection of glucagon labelled with ^{131}I, the hormone becomes concentrated in the following organs (in decreasing order of amount stored): kidneys, liver, pituitary, spleen, lungs, salivary glands, adrenals, pancreas, thyroid, heart, duodenum, lymph glands. Hepatectomy and nephrectomy show that the liver and kidneys are the main sites of degradation of glucagon, in which a proteolytic 'glucagonase' of limited specificity is said to take part. This enzyme contains SH groups and is inhibited by insulin, growth hormone, α-ACTH and α-casein. Injected glucagon is thus quickly broken down – in man it has a half-life of less than 10 min[7] – so that it is therefore unlikely to be identical with the glycogenolytic or hyperglycaemia-producing substances found in the urine of normal individuals, diabetics and schizophrenics.

Biological activity

Long-continued administration of neutral red results in degranulation of the pancreatic α-cells and a reduction in their absolute number. Rats treated in this fashion develop fasting hypoglycaemia and subnormal tolerance to insulin and tolbutamide[18].

Glucagon administration to mammals, birds and reptiles causes a rise in the blood glucose concentration. The magnitude of the rise and its duration depend on the dose, the mode of administration, the nutritional state of the subject and the species of animal being tested. This hyperglycaemic effect is maximal in fed animals with plentiful hepatic glycogen reserves, is diminished but not abolished when hepatic glycogen stores are depleted, and is absent in the eviscerated animal. The hyperglycaemia induced by glucagon is accompanied by rapid depletion of hepatic glycogen stores in vivo. In vitro (isolated perfused liver, liver slices, liver homogenates) glucagon is a potent glycogenolytic agent in physiological concentrations[1]. Conversely, glucagon stimulates gluconeogenesis from amino acids and lactate in the perfused rat liver[19,20]. When these substrates are not provided it promotes new glucose formation from endogenous liver protein[21]. Glucagon has an inotropic effect on the heart, where it enhances oxidation of glucose and acetate to CO_2[22].

The manner in which glucagon intervenes in carbohydrate metabolism has been largely elucidated. Like adrenaline (see page 733), glucagon stimulates the formation of adenosine cyclic 3′,5′-phosphate[23] and therefore increases glycogenolysis. This biomolecular action of glucagon has been observed in the liver and heart but – in contrast to adrenaline – not in skeletal muscle[2]. The action of adenosine cyclic 3′,5′-phosphate, and of glucagon, in stimulating gluconeogenesis from lactate in the perfused rat liver probably takes place through activation of phosphopyruvate carboxylase[20]. Glucagon causes a significant release of potassium from the liver. This phenomenon precedes phosphorylase activation, but it is uncertain whether the two effects are related[24].

Glucagon is antagonistic to insulin in that it promotes the release of glucose in the liver in hypoglycaemia[25]; on the other hand it also appears to stimulate insulin secretion in man independently of its hyperglycaemic effect[26]. When added to rabbit pancreatic slices it causes release of insulin into the incubation medium, the reaction rate increasing with the glucose concentration of the medium[27]. In man under physiological conditions it is possible that pancreatic glucagon is primarily insulinogenic and secondarily hyperglycaemic, whereas the glucagon of the digestive tract is primarily hyperglycaemic[12].

When given to animals in large doses over long periods, glucagon produces hyperglycaemia, glycosuria, a markedly negative nitrogen balance, weight loss and increased basal metabolic rate, while in at least one species (rabbit) it may induce permanent diabetes (metaglucagon diabetes)[28]. There is no evidence, however, indicating that hypersecretion of glucagon is a pathogenic factor in diabetes.

Glucagon diminishes gastrointestinal motility[29], inhibits the secretion of gastric juice and hydrochloric acid[2], and abolishes hunger[2]. In the kidneys it has a diuretic action and increases the excretion of sodium, potassium, chloride, bicarbonate, phosphate and uric acid[2,30]. Here glucagon may again act by producing adenosine cyclic 3′,5′-phosphate, which may be capable of changing the permeability of the nephron (see under 'Oxytocin and Vasopressin', page 723).

A further action of glucagon is on lipid metabolism, in that the hormone promotes mobilization of fatty acids from adipose tissue[31]. Once again the underlying mechanism is probably the formation of adenosine cyclic 3′,5′-phosphate (see under 'Catecholamines', page 733).

Clinical significance

Insufficient endogenous glucagon secretion has been postulated as a cause of hypoglycaemia in certain patients in whom histological examination of the pancreas showed it to be deficient in α-cells, but this remains to be confirmed by measurements of pancreatic glucagon content and serum levels of the hormone in this type of patient[32]. A pancreatic islet cell tumour in which immunoassay revealed large amounts of glucagon has been reported, the patient having high serum glucagon and insulin levels and mild diabetes[33]. The full syndrome of glucagon excess as produced experimentally in animals has not yet been shown to occur spontaneously in man.

Diagnostically, glucagon is useful in the evaluation of patients with glycogen storage disease. Depending on the position of the enzymatic block in the glycogenolytic pathway, the hyperglycaemic effect of glucagon may be absent, normal, blunted, or present only shortly after a carbohydrate meal. Atypical results, however, have been reported. The response to glucagon has also been used to evaluate glycogen reserves in ADDISON's disease, diabetes and liver disease. In pharmacological doses glucagon stimulates myocardial contractility and the heart rate, an effect which suggests therapeutic possibilities in congestive heart failure[36].

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His·Ser·Asp·Gly·Thr·Phe·Thr·Ser·Glu·Leu·Ser·Arg·Leu·Arg

Asp·Ser·Ala·Arg·Leu·Glu(NH_2)·Arg·Leu·Leu·Glu(NH_2)·Gly

Leu·Val(NH_2)

This polypeptide has been synthesized and the synthetic hormone shown to have quantitatively the same physiological properties as highly purified secretin from swine

Secretin is released on acid stimulation of the duodenum and plays an important part in neutralization of the contents of the small intestine It increases the blood flow to the pancreas, and in this organ stimulates not only the exocrine secretion of water (see page 651) and bicarbonate (see page 652) but also the endocrine secretion of insulin[16]. Secretin stimulates the flow of bile by favouring the production of a fluid rich in bicarbonate[20].

Secretin has been shown by radioimmunoassay to be present in normal human serum at a concentration of less than 0 4 μg/l in fasting and up to 25 μg/l after oral glucose loading[19].

Cholecystokinin-pancreozymin

Cholecystokinin-pancreozymin has the same spectrum of biological activity as gastrin but its effects differ markedly in intensity compared to the latter It is a very weak stimulant of *gastric acid secretion*, but unlike gastrin it causes strong contractions of the gallbladder The exocrine discharge of enzymes by the pancreas is stimulated (see page 652), but the hormone has no effect on the amount of pancreatic juice secreted or on its bicarbonate content Cholecystokinin-pancreozymin also stimulates the secretion of insulin and glucagon[16]

Enterogastrone

This hormone is present in the mucosa of the small intestine but has not yet been isolated Its release is stimulated by contact of fats and sugars with the mucosa of the small intestine. The hormone is thought to inhibit the secretory and motor activity of the stomach.

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rmones of the gastrointestinal tract[1]

strin[2,3]

SO_3H

—Glu Gly Pro Try Met Glu Glu Glu Glu Glu Ala Tyr—
1 2 3 4 5 6 7 8 9 10 11 12

Gly Try Met Asp Phe NH_2
13 14 15 16 17

Gastrin I differs from gastrin II in having no sulphate group ached to the tyrosine residue The human gastrins are distin- shed from the porcine compounds by having a leucine instead methionine residue at position 5[4] The structure of the canine

ome[13] Gastrin is released on stimulation of the vagus nerve, on ntact of food with the pyloric antrum, and on dilation of the trum Acetylcholine liberated from the nerves acts as inter-

gher dose of gastrin[15] At high dosages, which inhibit acid se- etion, gastrin stimulates the secretion of pepsin, it also increases

Secretin originates from the mucosa of the upper small intestine is a polypeptide consisting of 27 amino-acid residues with the llowing structure

Erythropoietin [1]

Erythropoietin is a factor easily demonstrable in the serum of various animal species under certain circumstances (hypoxia, anaemia, injection of cobalt chloride); it has been shown to stimulate erythropoiesis in a specific fashion. It appears to be a mucopolysaccharide or glycoprotein containing sialic acid and has a reported molecular weight of 10000–62000[2,3]. Erythropoietin possesses weak antigenic properties[4].

Erythropoietin can be detected in vivo by studying erythropoiesis (^{59}Fe-incorporation in erythrocytes, reticulocytosis) in mice or rats in which this function is suppressed. Its in vitro determination (for instance in bone-marrow cultures) has proved less successful. An immunoassay method has recently been developed[16].

1 International Unit (IU) of erythropoietin is contained in 1.48 mg of the 1st International Reference Preparation (see page 763). This unit is the same as the unit of the Erythropoietin Standard A or B of the National Institute for Medical Research, London[5]. Highly purified preparations from rabbit plasma or human urine have an activity up to 368 IU/mg[3].

The kidneys play a particular role in the formation of erythropoietin, which is either mainly produced in this organ[6] or is the result of the formation by the kidneys of an enzyme (renal erythropoietic factor) that liberates erythropoietin from the plasma proteins[7]. Erythropoietin formation is elicited by oxygen deficiency in the tissues and may be stimulated by the androgens[8], which would account for the higher erythrocyte count in men.

Erythropoietin is barely detectable in normal human plasma by biological methods[9], but immunoassay has revealed a concentration of 7–30 U/l[16]. The hormone disappears fairly rapidly from the circulating blood, the half-life being about 2–3 hours[10]. Normal values for the urinary excretion are given in the table below; discrepancies in reported values can probably be ascribed to differences in methods of measurement. The acceleration of erythropoiesis during pregnancy is associated with increased erythropoietic activity in the plasma and, in the second trimester, in the urine[11]. High levels of erythropoietic activity are found in cord blood[12], and erythropoietin has also been detected in the amniotic fluid[13]. Increased amounts of erythropoietin have been demonstrated in the plasma of many patients with polyglobulism, anaemia, blood loss or haemolysis[9,14].

Urinary excretion of erythropoietin (IU/24 h)

	Mean	Range	s	Reference
Boys	1.0	0.6–1.2	–	17
Men	2.8	1.5–5.2	1.3	17
Women	0.9	0.5–1.8	0.4	17
Men	0.54	0.21–1.2	–	18
Women	0.22	0.16–0.32	–	18
Men in Chacaltaya, Bolivia (5200 m)	9.1	1.1–22.4	–	18

Biological activity

Erythropoietin stimulates proliferation of the erythroblasts in the bone marrow, increases the numbers of reticulocytes and erythrocytes in the peripheral blood and promotes the metabolism of the bone marrow, reticulocytes and erythrocytes (purine synthesis, haem synthesis, DNA synthesis, RNA synthesis)[15].

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Renin-angiotensin system [1,2]

Chemistry

This system consists of a complex enzymatic reaction in w the enzyme renin acts on a plasma protein substrate (angioten gen) to liberate the decapeptide angiotensin I (hypertensin I, ar tonin I). This latter substance is broken down to the octapep angiotensin II by the action of a plasma enzyme complex (con ing enzyme) activated by chloride. Angiotensin II is in turn idly converted into inactive peptides by peptide hydrolases ('an tensinase') present in the tissues (kidneys, liver), erythrocytes plasma, its half-life in the blood being about 1 min. These react are subject to the action of various activators and inhibitors pre in the plasma.

Renin is a protein with a molecular weight of about 43000 man)[3], angiotensinogen a plasma protein belonging to the globulin group. The latter is converted by trypsin into a tetrad peptide, the so-called polypeptide renin substrate, which is s by renin at the Leu-Leu linkage. The structures of this compo and of the angiotensins are shown in the table opposite. The s thetic Val^5-angiotensin-II-Asp^1-β-amide has the same qualitat and quantitative pharmacological properties as naturally occurr angiotensin II[4] and is therefore suitable for use as reference su stance.

Units

Renin. 1 Goldblatt Unit is the amount of renin that increa the mean arterial blood pressure (measured directly in the femo artery) by 30 mm Hg when injected intravenously into nonana thetized dogs[1]. By using angiotensinogen as substrate, renin co centration can be expressed as enzyme activity, 1 unit correspon ing to the formation of 1 ng angiotensin per minute[5,6].

Angiotensin. 1 Goldblatt Unit is the amount of angiotensin th increases the mean arterial blood pressure (measured directly in t femoral artery) by 30 mm Hg when injected intravenously in nonanaesthetized dogs[1]. Angiotensin concentration can also expressed in terms of the reference substance angiotensin II (s above), 1 μg angiotensin II corresponding to about 2.2 Goldbla Units[7].

Methods of assay

Renin

Biological methods. (a) Direct measurement of the hypertensiv effect in vivo after intravenous injection of the test solution in to nonanaesthetized dogs[1] or in vitro in an aorta preparation (b) Method of Bocher et al.[5] for plasma renin (renin-like activity) Incubation of the plasma containing renin and angiotensinoge together with activators and inhibitors at pH 5.5 and 37°C in th presence of Dowex 50W-X2(NH_4), an ion-exchange resin that ad sorbs angiotensin and thus prevents its breakdown by angiotensi nase; after elution the angiotensin is determined by its hyperten sive effect on rats. (c) Method of Brown et al. for plasma renin[6] After adsorption of the renin in a DEAE-cellulose column an subsequent elution the angiotensinogen and 'angiotensinase' ar eliminated by acidification; the renin so isolated is incubated wit bovine angiotensinogen at pH 5.7 and 37°C and the angiotensin liberated determined by its hypertensive effect on rats.

Chemical methods. Fluorimetric determination of the hydrolysis products in a synthetic substrate acted on by renin[9]. This method is too insensitive for assay of the renin content of plasma.

Structure of angiotensins

	Mol wt	Amino-acid sequence	Origin
Ile^5–polypeptide–renin substrate .	1759	Asp Arg·Val·Tyr Ile His Pro·Phe His Leu Leu Val Tyr Ser 1 2 3 4 5 6 7 8 9 10 11 12 13 14	Equine plasma after action of trypsin[26]
Ile^5-angiotensin I	1297	Asp·Arg·Val·Tyr Ile·His·Pro Phe His Leu 1 2 3 4 5 6 7 8 9 10	Equine[27], porcine[28], human[29] plasma
Val^5-angiotensin I..............	1283	Asp Arg Val Tyr Val His Pro Phe His Leu 1 2 3 4 5 6 7 8 9 10	Bovine plasma[30]
Ile^5-angiotensin II..............	1046	Asp Arg Val Tyr·Ile His Pro Phe 1 2 3 4 5 6 7 8	From Ile^5-angiotensin I
Val^5-angiotensin II.............	1032	Asp Arg Val Tyr Val His Pro Phe 1 2 3 4 5 6 7 8	From Val^5-angiotensin I
Val^5-angiotensin-II-Asp^1-β-amide	1029	Asp(NH_2) Arg Val·Tyr Val His Pro·Phe 1 2 3 4 5 6 7 8	Synthetic[4]

Angiotensin

Biological methods. (a) Direct measurement of the hypertensive effect in vivo after intravenous injection of the test solution into nonanaesthetized dogs[7] or in vitro in an aorta preparation[8].

sterone production selectively[31]. The rate of aldosterone secretion is a direct function of the plasma renin activity ...

The renin–angiotensin system appears to be involved in the thirst mechanism since both these substances have been shown to instigate drinking to replace lost fluid[32]. Angiotensin regulates renin secretion through a negative feedback mechanism[24].

Clinical significance

Measurement of plasma renin activity enables a distinction to be made between primary aldosteronism (decreased renin activity) and secondary aldosteronism (increased renin activity). It can also be used to confirm the renovascular origin of arterial hypertension associated with renal arterial stenosis

Test of KAPLAN and SILAH[25]. Sensitivity to the hypertensive effect of an intravenous infusion of angiotensin is decreased in renovascular arterial hypertension, increased in primary aldosteronism.

Renin and angiotensin contents of blood

	Mean	Range	*s*	Method	Reference
Renin (U/l)					
Plasma	9 0	0–32	7 6	Biological	14
Plasma	4	2–10	–	Biological	33
Angiotensin (ng/l)					
Plasma	60	–	100	Biological	34
Blood	95		66	Biological	35
Plasma	–	< 8–56	–	Radioimmunological	36
Blood	21	–	14	Radioimmunological	37

Biological activity

The active agent in the renin–angiotensin system is free angiotensin II, which has three main effects[19]

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Plasma kinins [1-3]

Chemistry

The kinins are low-molecular polypeptides of high pharmacological activity arising from the action of proteolytic enzymes on the plasma proteins. Naturally occurring kinins that have also been synthesized are listed in the table below.

The kinins are best detected by means of their contractile action on the isolated guinea-pig ileum or on the isolated uterus of the rat in full oestrus. Bradykinin can be determined by radioimmunoassay by means of its ^{14}C-acetyl derivative[4].

Biosynthesis, metabolism

The inactive precursors of the kinins, the kininogens, are α_2-globulins with a molecular weight of about 50000. These give rise to the plasma kinins through the action of the enzyme kallikrein. A kininogen isolated from bovine serum yielded 20 µg bradykinin/mg[5]. The enzyme kallikrein occurs in urine, sweat, saliva and faeces, its inactive precursor prekallikrein (kallikreinogen) in the pancreas, salivary glands, gut wall, tongue and plasma[2]. In blood, kallikrein is liberated from prekallikrein in the presence of factor XII (Hageman factor). Free kallikrein is inhibited by substances in various tissues, particularly the lungs and salivary glands.

In blood the kinin kallidin is rapidly converted into bradykinin by an aminopeptidase. In the plasma of adults the bradykinin level is less than 2 µg/l[6]; in cord blood the mean level is 12.8 µg/l[6]. Higher values occur in shock, acute pancreatitis and the carcinoid syndrome[3,7]. The plasma kinins are rapidly broken down by peptidases into inactive fragments[7]. Kinin-inactivating enzymes are present in many tissues, for instance in the liver, spleen, kidneys, lungs and lymph glands. When injected intravenously bradykinin is metabolized in the blood with a half-life of 30 s[8]. Urine contains two urokinins with a pharmacological activity resembling that of bradykinin and kallidin, but these probably originate not in the blood but in the epithelium of the renal tubules[9].

Biological activity

The plasma kinins have a contractile effect on smooth muscle, for instance that of the gut, uterus and bronchi, and lower the blood pressure and increase vascular permeability when given intravenously; they cause pain when applied to the base of a cantharides blister. The effect of bradykinin on the isolated r is about the same as that of oxytocin[3]. The blood pressu ing effect is due to dilation of the resistant vessels; the h minute volume and regional blood flow are all increased.

The physiological function of the kinins is not known, b in the regulation of the blood flow to the secretory glands suggested[10]. Bradykinin is possibly involved in the transit foetal to newborn circulation[6].

The plasma kinins play a role in two diseases, hereditar neurotic oedema, due to a dominantly inherited, congen ciency of plasma kallikrein inhibitors[11], and the carcin drome, in which the flush-producing principle is identi bradykinin[12]. The role played by the plasma kinins in in tory reactions remains obscure, but it seems that the kinin- system is activated wherever tissues are damaged[14]. Kini been detected in the synovial fluid of patients with arthri

Structure and biological activity of naturally occurring plasma kinins[13]

	Mol.wt.	Structure	Relative activity in vitro*	Relative activity in vivo**	Occurrence
Bradykinin (kallidin I, kallidin-9, kinin-9)	1060	Arg·Pro·Pro·Gly·Phe·Ser·Pro·Phe·Arg	100	100	Bovine plasm human plasm
Kallidin (kallidin II, lysylbradykinin, kinin-10)	1188	Lys·Arg·Pro·Pro·Gly·Phe·Ser·Pro·Phe·Arg	33	190	Bovine plasm human plasm
Methionylkallidin (methionyllysylbradykinin, kinin-11)	1329	Met·Lys·Arg·Pro·Pro·Gly·Phe·Ser·Pro·Phe·Arg	25	–	Bovine plasm

* Contraction of the isolated guinea-pig ileum. ** Lowering of blood pressure in rabbits.

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[11] Landerman et al., *J.Allergy*, 33, 330 (1962).
[12] Oates et al., *Lancet*, 1, 514 (1964); Oates et al., *J.clin.Invest.*, 45, 17
[13] Schroeder and Luebke, *The Peptides*, vol.2, Academic Press, Ne 1966.
[14] Lewis, G.P., in Robson and Stacey (Eds.), *Recent Advances in Phar* 4th ed., Churchill, London, 1968, page 213.

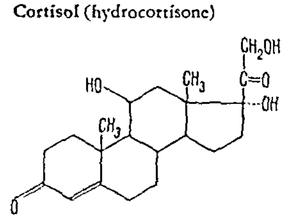
Corticosteroids

(adrenocortical hormones) (for references see pages 750-751)

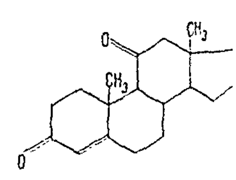
Chemistry

The corticosteroids consist of C_{21}-steroids containing a three oxygen atoms and are present in the adrenal cortex, and urine[1]. The structural formulae of the seven most imp biologically active corticosteroids are shown below. Biol activity requires the presence of the Δ^4-3-keto configurati ring A and of a keto group in the side chain. Characteristic of sterone is the aldehyde group (C-18). Other steroids formed adrenal cortex are pregnanetriol and the androgens dehyd androsterone, androstenedione and 11β-hydroxyandrostene

Cortisol (hydrocortisone)

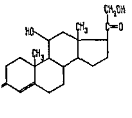


Cortisone

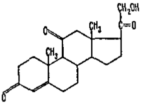


(For references see pages 750–751)

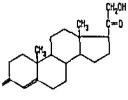
ticosterone



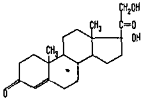
Dehydrocorticosterone
(11-dehydrocorticosterone)



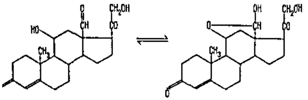
Deoxycorticosterone (cortexone)



11-Deoxycortisol (cortexolone)



ldosterone



Assay[2]

The hormones must first be extracted from the tissue by means of a suitable solvent During extraction and subsequent operations care must be taken to avoid the formation of artefacts, either as a result of autoxidation in air or of the techniques employed

By using group-specific methods, various classes of steroids can be determined (see the table on page 744)[3,4] If the individual

veloped[8]

used for cortisol and cortisone Pregnanetriol can be determined by the methods of Bongiovanni and Eberlein[10 11] or Harkness and Love[12], dehydroepiandrosterone by the method of Fotherby[13]

The many biological methods for assay of corticosteroids (for a review see Dorfman[14]), while no longer of clinical interest, are useful for ...

nalectomized rats after injection of these isotopes[15]

Biosynthesis, secretion, metabolism

Of the steroids formed in the adrenal cortex, those affecting salt and water balance (aldosterone and, less active in this respect, corticosterone) originate in the outermost layer (zona glomerulosa), those affecting carbohydrate metabolism (cortisol, cortisone and, less active in this respect, corticosterone) in the middle layer (zona fasciculata), and the 17-ketosteroids (mainly dehydroepiandrosterone) in the innermost layer (zona reticularis)

The pattern of corticosteroids secreted differs from one animal species to another. In man, those secreted in the largest amounts are cortisol and corticosterone. The cortisol/corticosterone ratio in the venous blood of the adrenals is 0 5–5, in the peripheral blood 5–30, the difference being due to the more rapid breakdown of corticosterone[16].

(continued on page 745)

Corticosteroid content of the normal adrenal gland[55]

	µg/g tissue	
	Mean	Range
Aldosterone	0 06	0 05–0 08
Corticosterone	1 3	0 73–2 9
Cortisol	2.7	0 97–3 9
Cortisone	0 05	0–0 10

Rates of secretion of corticosteroids

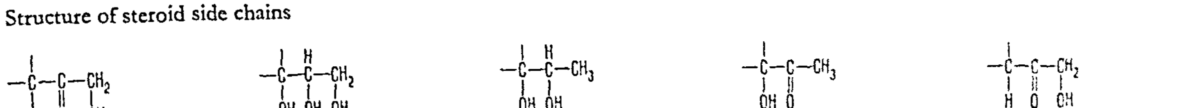
	Mean	Range	s	Reference
Aldosterone (µg/24 h)				
Newborn	23	9–41	12	75
Infants	72	25–138	29 5	75
Children, 1–15 years	91	57–162	30 4	75
Adults	80	39–138	30 8	75
Adults	135	70–210	–	76
Men, 18–35 years	77	40–110	–	77
Men, 67–88 years	34	20–72	–	77
Women, proliferative phase	139	–	44	78
Women, luteal phase	235	–	101	78
Women, pregnant	–	387–2912	–	79
Corticosterone				
(mg/24 h)				
Adults	2 3	1 5–4 0	–	80
Adults	3 22	2 1–4 2	–	81
(mg/24 h/m² body surface)				
Infants up to 3 months	2 5	–	–	82
Children	0 65	–	–	82
Cortisol				
(mg/24 h)				
Infants up to 3 months	3 8	–	–	82
Children	16	8 5–22 5	–	83
Adults	–	4 9–27.9	–	84
Adults	16 0	10 5–23 5	–	81
Women	17 5	11.4–20 9	1 9	85
Men	21 0	15 9–27 4	3 1	85
Old men	17 7	12 3–23 0	–	86
Pregnant women	15 0	11 3–18 9	–	85
(mg/24 h/m² body surface)				
Newborn, up to 5 days	18 7	–	3.7	87
Infants, 5–20 days	13 9	–	2 9	87
Persons, 4 months–20 years	12 1	–	2 9	87
Dehydroepiandrosterone sulphate (mg/24 h)				
Women	12	10–18 5	–	88
Men	17	14–22	–	88
Deoxycorticosterone (µg/24 h)	–	50–160	–	89
11-Deoxycortisol (mg/24 h)	–	0 20–2 0	–	90
18-Hydroxycorticosterone (µg/24h)	305	145–460	–	76

(For references see pages 750–751)

Group-specific methods of corticosteroid assay

Steroid class	Specific chemical structure	Method	Reference
PORTER-SILBER chromogens.....	17,21-Dihydroxy-20-keto (dihydroxyacetone) side chain (see below)	Colour reaction with phenylhydrazine in ethanolic sulphuric acid	PORTER and SILBER[61], PETERSON et al.[62]
21-Deoxyketols................	17-Hydroxy-20-keto-21-deoxy side chain (see below)	Specific oxidation to 17-ketosteroids followed by ZIMMERMANN's reaction (see under '17-Ketosteroids' below) Vanillin-phosphoric acid method	APPLEBY and NORYMBERSKI[63] McALEER and KOZLOWSKI[64]
17-Ketogenic steroids	Side chain as shown below	Specific oxidation to 17-ketosteroids followed by ZIMMERMANN's reaction (see under '17-Ketosteroids' below)	NORYMBERSKI et al.[65]
Total 17-hydroxycorticosteroids .	Side chain as shown below	Specific oxidation to 17-ketosteroids followed by ZIMMERMANN's reaction (see under '17-Ketosteroids' below)	APPLEBY et al.[66], FEW[67]
17-Deoxycorticosteroids	17-Deoxy-20-keto-21-hydroxy side chain (see below)	Specific oxidation to aldehydes and colour reaction of hydroxamic acids	EXLEY et al.[68]
Reducing corticosteroids........	20-Keto-21-hydroxy side chain (α-ketol group)	Alkaline reduction of blue tetrazolium to a coloured diformazan	MADER and RUCK[69]
11-Hydroxycorticosteroids	Δ^4-11-Hydroxy configuration	Fluorescence in ethanolic sulphuric acid	MATTINGLY[70], SILBER[71]
Δ^5-3β-Hydroxysteroids	Δ^5-3β-Hydroxy configuration (e.g., pregnenolone, but not cholesterol)	Colour reaction in ethanolic sulphuric acid	OERTEL and EIK-NES[72]
Δ^4-3-Ketosteroids..............	α,β-Unsaturated ketones	Colour reaction with isonicotinic hydrazide	UMBERGER[73]
17-Ketosteroids	Contain $-CO-CH_2-$ group; the 17-keto group is the most reactive	Colour reaction with *m*-dinitrobenzene in alkaline solution	ZIMMERMANN[74]

Structure of steroid side chains



PORTER-SILBER chromogens

21-Deoxyketols

17-Deoxycorticosteroids

17-Ketogenic steroids

Total 17-hydroxycorticosteroids

he secreted steroids as a result not only of metabolic action but lso of the analytical procedures Best results are given by isotope lilution techniques[19,20]

In health, the normal adult secretes 5–28 mg cortisol per day

Corticosteroids in plasma (μg/l)

	Mean	Range	s	Reference
Aldosterone				
Men	0 06	0 02–0 15	–	31
Adults	0 22	0 06–0 59	–	27
Corticosterone				
Cord blood	58	–	33	32
Children, 3–7 days	63	–	41	32
Children, 3 months–5 years	45	–	22	32
Children, 11–17 years	36	–	24	32
Adults	36	–	18	32
Adults	11	5–20	3	33
Cortisol				
Newborn, up to 12 hours	71	33–198	31 5	34
Infants, 12–24 hours	38	10–107	30 0	34
Infants, 36–48 hours	42	15–66	23 5	34
Infants, 1–5 months	47	38–62	10 4	34
Cord blood	129	–	47	32
Infants, 3–7 days	140	–	48	32
Children, 3 months–5 years	124	–	50	32
Children, 11–17 years	124	–	54	32
Adults	117	–	27	32
Adults	150	–	–	33
Adults	–	21–226	–	35
Cortisone				
Newborn, up to 12 hours	53	24–97	22 4	34
Infants, 12–24 hours	45	24–96	19 0	34
Infants, 36–48 hours	39	20–60	13 5	34
Infants, 1–5 months	6	0–9	4 0	34
11-Deoxycortisol	–	0–14	–	35
Pregnanetriol	–	<50	–	36

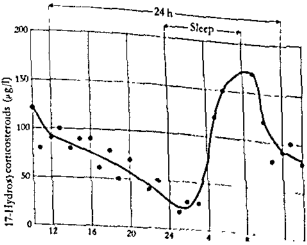
Corticosteroid fractions in plasma (μg/l)[56]

	Mean	s
Porter-Silber chromogens		
Unconjugated	129	43
Conjugated	173	56
Δ^4-3-Ketosteroids		
Unconjugated	133	49
Conjugated	118	63
Reducing corticosteroids		
Unconjugated	216	59
Conjugated	750	248

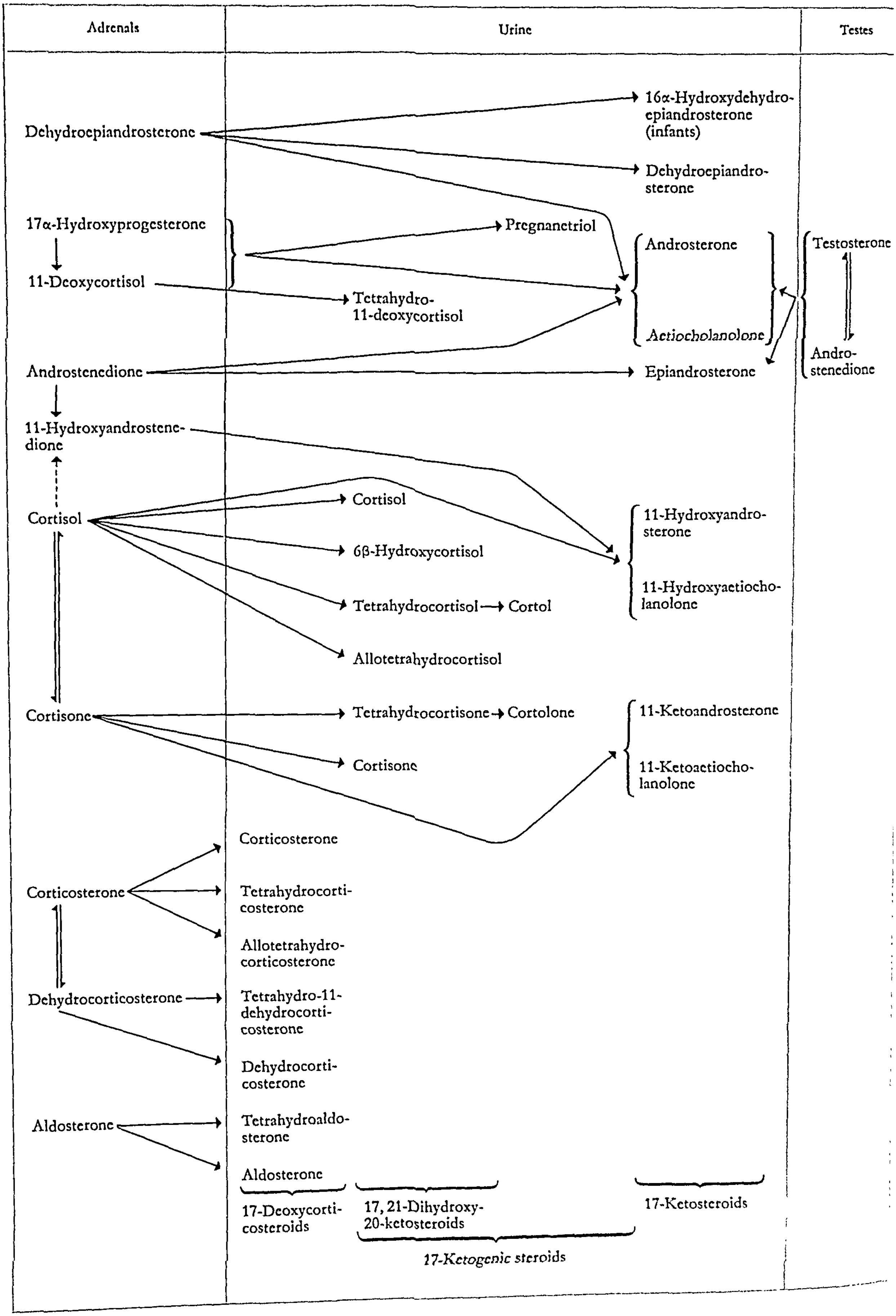
95–97% of the cortisol in the plasma is bound to a protein – probably an α-globulin – known as 'corticosteroid-binding globulin' or 'transcortin'[22] This protein binds cortisol more strongly

cumbent postures[25] ...ctuation between the upright and re-

17-Hydroxycorticosteroid content of the plasma of 5 adults during the course of the day[25]



Relationship of important urinary steroid fractions to the steroids of the adrenal cortex and testes



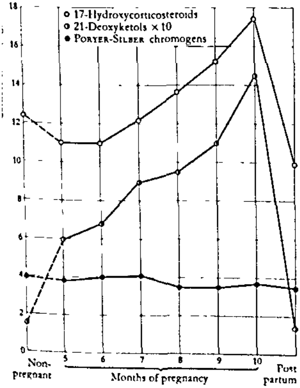
ıdrosterone is excreted mainly unchanged. Almost all the me-
lites appear in the conjugated form as glucuronides or sul-
es. For a further discussion of corticosteroid metabolism see
:s 428–430

ɿe scheme opposite There are differences of opinion as to which
the usual corticosteroid fractions determined in urine – the

nary excretion of cortisol[57]*, cortisone*[57] *and aldosterone*[58] *in children and lts*

	Cortisol		Cortisone		Aldosterone	
	µg/24 h	µg/24 h/kg body weight	µg/24 h	µg/24 h/kg body weight	µg/24 h	µg/24 h/kg body weight
Jp to 1 year	1 0	0 11	6 9	0 86	2 1	0 24
1–5 years	3 9	0 23	14 4	0 85	3 5	0 23
5–10 years	7 3	0 26	23 9	0 76	4 9	0 17
11–15 years	14 4	0 29	35 2	0 71	6 5	0 13
16–20 years	20 6	0 33	47 2	0 76	6 6	0 10
21–30 years	31 3	0 42	65 7	0 89	7 5	0 10

ʳinary corticosteroid excretion during pregnancy[30]

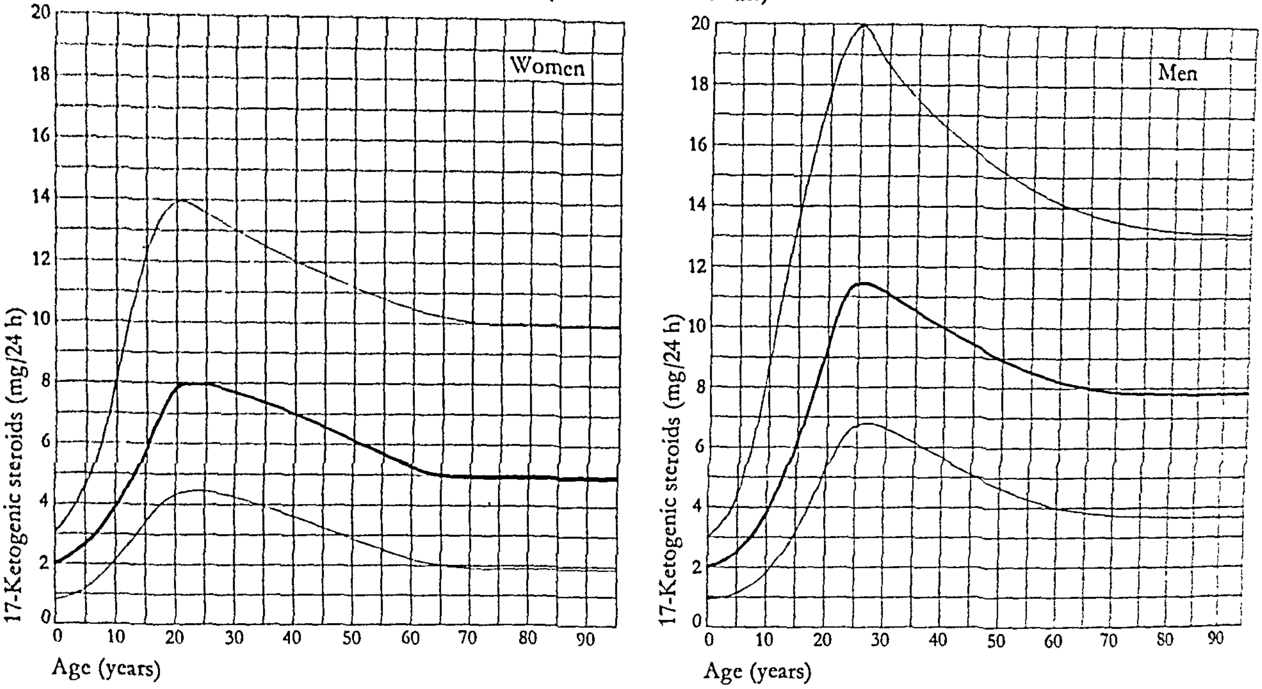


Urinary excretion of corticosteroids
(values for adults unless otherwise stated)

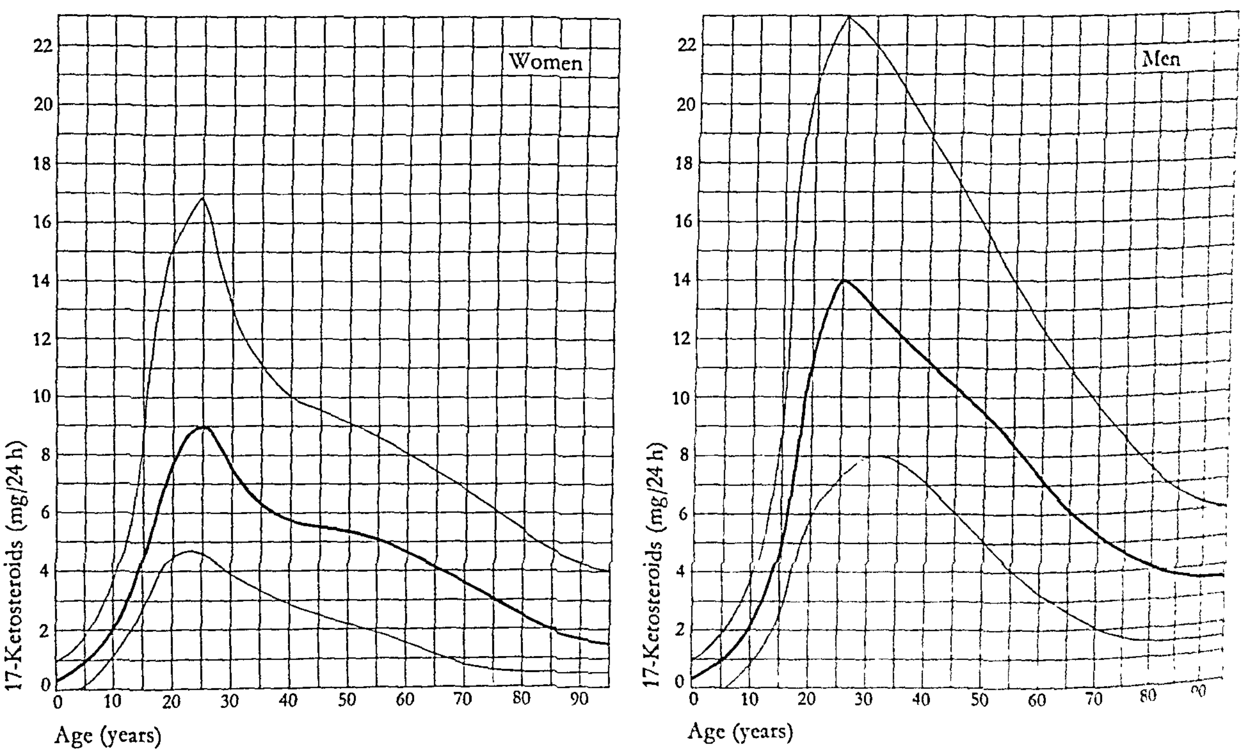
	Mean	Range	Reference
Aldosterone (µg/24 h)	5	2–10	97
Aldosterone, free (µg/24 h)			
Newborn	–	0 03–0 13	98
Adults	–	0.17–0 63	99
18-Aldosterone glucuronide (µg/24 h)			
Newborn	–	0 4–2 5	98
Adults	5 6	3 0–12 0	99
Corticosterone (mg/24 h)	0 02	0–0 04	97
Cortisol (mg/24 h)	0 07	0 03–0 09	97
Cortisol, free (mg/24 h)	0 019	–	100
Cortisol glucuronide (mg/24 h)	0 025	–	100
Cortisone (mg/24 h)	0 09	0 06–0.14	97
Cortisone, free (mg/24 h)	0 057	–	100
Cortisone glucuronide (mg/24 h)	0 063	–	100
Cortolone (mg/24 h)			
Men	1 9	0 3–2 9	99
Women	1 1	0 5–1 6	99
11-Dehydrocorticosterone (mg/24 h)	0 01	0–0 03	97
6β-Hydroxycortisol (mg/24 h)			
Men	0 44	–	99
Women	0 37	–	99
16-Hydroxydehydroepiandrosterone (mg/24 h)			
Newborn, up to 7 days	0 29	0 0–1 1	101
Infants, 4–6 months	0 04	0 0–0 16	101
16-Hydroxypregnenolone (mg/24 h)			
Newborn, up to 7 days	0 98	0 05–3 6	101
Infants, 4–6 months	0 02	0 0–0 08	101
Pregnanetriol (mg/24 h)			
Children before puberty	–	<0 1	102
Men	–	0 11–0 97	103
Women	–	0 11–0 45	103
Tetrahydroaldosterone (µg/24 h)			
Newborn	–	1.9–7 2	98
Adults	–	40–60	99
Tetrahydrocorticosterone (mg/24 h)	0 20	0 10–0 36	97
allo-Tetrahydrocorticosterone (mg/24 h)	0 20	0 08–0 36	97
Tetrahydrocortisol (mg/24 h)	1 0	0 6–1.6	97
Men	2 2	0 8–2 8	99
Women	1 9	0 5–3 7	99
allo-Tetrahydrocortisol (mg/24 h)	0 4	0 1–0 7	97
	1 1	0–2 8	99
Tetrahydrocortisone (mg/24 h)	2 7	1 0–3 8	97
Tetrahydro-11-dehydrocorticosterone (mg/24 h)	0 16	0 06–0 24	97
Tetrahydro-11-deoxycortisol (mg/24)	0 06	0 02–0.10	97

(For references see pages 750–751)

Urinary excretion of 17-ketogenic steroids in women and men[29] (98% confidence limits)



Urinary excretion of 17-ketosteroids in women and men[31] (mean and 98% confidence limits)



17-ketosteroids, the 17-ketogenic steroids or the 11-hydroxycorticosteroids – best represents the corticosteroid production of the adrenals[32, 33, 99]. In men, about two-thirds of the total 17-ketosteroids are corticosteroid metabolites, one-third testicular steroid metabolites; in women they arise mainly from the corticosteroids, with a small contribution from the ovaries.

In assessing the significance of the urinary aldosterone excretion the state of hydration of the body as well as the potassium and sodium balance must be taken into account. The urinary pregnanetriol level is a valuable indication in patients with congenital adrenocortical hyperplasia. 16α-Hydroxypregnenolone and 16α-hydroxydehydroepiandrosterone – both steroids of adrenal origin – have been found only in the urine of the newborn and infants; they are probably precursors of the oestrogens formed by the placenta.

Functional tests

The functional capacity of the adrenal cortex is determined by assaying the corticosteroids in the blood or urine after an exogenous dose of ACTH, usually 25–50 IU given intravenously[33, 98]. More recently, the synthetic polypeptide tetracosactrin (β^{1-24}-corticotropin) has also been used for this purpose[34]: in 66 subjects given an intramuscular dose of 0.25 mg the plasma level of 11-hydroxycorticosteroids rose from 147 μg/l to 314 μg/l within 30 minutes.

ry excretion of 17-ketosteroids in children and adults (mg/24 h)

	Number	11-Hydroxy-aetiocholanolone		11-Hydroxy-androsterone		11 Keto-aetiocholanolone		Dehydroepi-androsterone		Aetiocho-lanolone		Androsterone		Reference
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
ys, 3–12 years....	9	0.35	0.03–0.88	0.45	0 09–0 92	0 34	0 03–0 62	0 10	<0 01–0 33	0 35	0 04–0 82	0 32	0 07–0 82	104
rls, 3–11 years .	14	0.25	0 01–0 73	0 64	0.10–1.74	0 33	0.03–0 84	0 08	<0 01–0 34	0 50	0 01–1.56	0 67	0 01–2 28	104
en, 19–43 years ..	10	0 6	0 3–1.1	1 6	1 0–2.1	0 6	0 3–1 4	2 3	0 8–6 4	2 8	1 4–5.1	3.4	1 5–6 0	104
omen, 18–43 years	25	0 6	0 2–1 2	1 4	0 2–2 9	0.7	0 2–1 4	1.1	0 1–2 6	2 7	0 7–4 3	3.1	0 9–4 8	104
en, 50–71 years. .	11	0 8	0 2–2 2	1.7	0 8–3 1	0 7	0 2–1.5	0 7	<0 1–4 0	2 5	1 1–5 0	1 8	1 0–3 8	104
omen, 46–70 years	21	0 6	0 2–1 5	1.0	0 5–1.9	0.7	0 3–1 4	0 3	<0 1–0 7	2 2	0 9–3 7	1.3	0 5–3 8	104
en.	8	0.7	0.3–1 6	0 6	0 3–1 0	0 7	0 2–1.1	0 6	0 1–1 4	2 1	1 0–3 1	2 1	1.1–3 5	105
omen	8	0 9	0 6–1 9	0.5	0 1–0 9	0 5	0 2–0 7	0 4	0 1–1 1	1 9	1 3–3 9	1 6	0 3–3 6	105

)iseases of the adrenal cortex can be identified by means of ste-d suppression tests These depend on the fact that cortisol secre-n by the adrenal cortex – so long as it is dependent on the pitu-y ACTH – can be suppressed by exogenous doses of cortico-roids A test of this kind using oral doses of dexamethasone has n standardized by LIDDLE[35] The metyrapone test is described page 717.

Unlike the chemical assay of corticosteroids in body fluids, in-ect functional tests are not of great diagnostic value The com-nest are the eosinophil test (THORN's test)[36], the diuresis test[37] d tests involving studies of the electrolyte balance

...ity, as shown in the table below There are also species differences the activity of the corticosteroids, this is particularly marked be-een rats and man[40]

On the basis of their activity spectra the corticosteroids are often lassified into mineralo- and glucocorticosteroids A strict classifi-ation in this way is, however, impossible since the activity spec-ra overlap Corticosteroids with an oxygen atom at C-11 mainly ave an effect on carbohydrate and protein metabolism The action f corticosteroids on mineral metabolism is essential for the main-enance of life, and death ensuing after complete failure of the adre-nal cortex ...

Action on carbohydrate and protein metabolism[41] In animals that have been adrenalectomized, starvation leads to rapid depletion of the carbohydrate reserves, with lowering of the blood sugar level and glycogen content of the liver and muscles Adrenalectomized ani-mals are also hypersensitive to exogenous insulin Similar distur-bances of carbohydrate metabolism occur in patients with ADDI-SON's disease Administration of corticosteroids reverses these changes Corticosteroids cause a rise in both nitrogen excretion and the amino-acid content of the blood, whence it can be con-cluded ...

with a reduced response to insulin

This catabolic action of the corticosteroids is reflected in tissue breakdown, diminution of the muscle mass, osteoporosis and thinning of the epidermis The mechanism of these processes has been only partially elucidated

Corticosteroids also have an effect, both in vivo and in vitro, on the activity of many enzymes[42] Thus in the liver they increase the activity of glucose-6-phosphatase and enzymes, like tryptophan oxygenase and tyrosine aminotransferase, involved in amino-acid metabolism At the same time corticosteroids promote the forma-tion of messenger-RNA and the de novo synthesis of enzymes[42,43] Possibly this activity derives from a direct effect of corticosteroids on gene activity[44]

...cortical function are reflected in changes in electrolyte and water balance Hypofunctioning of the gland results in loss of sodium in ...

have markedly greater effects on mineral metabolism than cortisol Both aldosterone and deoxycorticosterone augment the reabsorp tion of sodium in the distal renal tubules and at the same time promote potassium excretion, while the resulting sodium retention results also in water retention Aldosterone most likely acts by promoting active sodium transport, as has been demonstrated in the urinary bladder of the toad[47] The first event is possibly a direct involvement of aldosterone in the nuclear synthesis of messenger RNA[60]

Cortisol acts in a different way Like aldosterone, but to a lesser extent, it promotes sodium reabsorption in the distal tubules, but

Relative activity of corticosteroids in adrenalectomized animals[59]

	Decrease in urinary Na^+/K^+ ratio (rats)	Growth and survival (rats	Survival (dogs)	Muscle-work test (rats)	Glycogen de-position (rats)
Cortisone	0 6	2 5	0 5	10	10
Cortisol	0 8	[illegible]	–	19	16
Corticosterone	1 4	1 [illegible]	–	–	5
11-Dehydro-corticosterone	–	1 0	–	5	5
11-Deoxycortisol	0 8	–	–	0 2	–
11-Deoxycortico-sterone	10	10	10	0 2	0 1
Aldosterone	1000	–	250	–	3

the increased potassium excretion seems more likely to be due to mobilization of tissue potassium than to an effect on renal function. The lowered diuresis occurring in adrenocortical insufficiency can be corrected by giving cortisol but not aldosterone. Cortisol appears to be necessary for maintenance of tubular function and thus of normal diuresis.

Action on blood circulation. This is mainly secondary to the action on water and electrolyte balance (reduction of plasma volume and increase in blood viscosity in adrenocortical insufficiency) but the corticosteroids also have a direct effect on the capillaries, arterioles and myocardium. The stimulating effect of corticosteroids on adrenaline release is also reflected in circulatory changes.

Action on muscles. The impairment of muscular function in adrenocortical insufficiency is primarily a result of the reduced circulation. In primary aldosteronism muscle weakness is due to the lowered blood potassium level, in CUSHING's syndrome to the increased breakdown of muscle.

Action on the central nervous system. The corticosteroids affect the excitability of the brain and the emotions. This is mainly a result of the action of these substances on the cerebral circulation and on the metabolism of γ-aminobutyric acid and electrolytes in the brain[48].

Action on lymphatic tissues. Exogenous corticosteroids give rise to marked involution of the lymphatic organs, with involvement of both the parenchymal and reticular connective-tissue cells[49]. In the initial phase there is characteristic breakdown of the thymocytes in the thymus and of the lymphocytes in the lymph glands and to a lesser extent in the spleen. Following this lymphocytolysis is a second phase marked by inhibition of new cell formation on the one hand (manifested by the absence of mitosis in the thymus, lymph glands and spleen) and by degeneration of the reticular connective tissue on the other.

Corticosteroids cause both an increase and decrease in the numbers of circulating antibodies; the mechanism of these effects is still largely obscure. In man, as in monkeys and guinea-pigs, corticosteroids seem to have little effect on antibody formation, but in rabbits, rats and mice antibodies may be suppressed by these substances under certain conditions.

Action on eosinophils. Administration of corticosteroids or ACTH reduces the number of circulating eosinophils, an effect utilized in THORN's test for adrenocortical insufficiency. The mechanism is unknown[50].

Anti-inflammatory action. Administration of glucocorticoids inhibits or suppresses most inflammatory processes of a toxic, allergic, infectious or traumatic nature. Their effect is, however, merely palliative, and the symptoms reappear when the steroids are withdrawn[51]. This action has been ascribed to a protective effect of corticosteroids on the lysosome membranes[52], the liberation of whose protein-splitting enzymes is thought to cause inflammation.

Action on the pituitary. The circulating corticosteroids exert an inhibitory action on pituitary secretion of ACTH (for further discussion see page 717).

Synthetic steroids. Chemical modification of the steroid skeleton has resulted in synthetic compounds of greater physiological activity and higher specificity than the natural corticosteroids. Over 1200 biologically active steroids, natural and synthetic, ar known. In the table on this page the effects of some synthe roids are compared with those of cortisone and cortisol.

Physiological activity of natural and synthetic steroids[53]

	Anti-inflammatory activity	Sodium retention	Potassium excretion	Effect on carbohydrate metabolism
Cortisone	1	1	1	1
Cortisol	1–1.25	1–1.25	1	1.25
Prednisone (1-dehydrocortisone)	3–5	slight	slight	3–5
Prednisolone (1-dehydrocortisol)	3–5	slight	slight	3–5
6α-Methylprednisolone	3–5	none	slight	3–5
9α-Fluorocortisol	10–15	300–900	10–25	10–25
Triamcinolone (9α-fluoro-16α-hydroxy-prednisolone)	3–5	none	slight	3–5
Dexamethasone (9α-fluoro-16α-methyl-prednisolone)	15–28	none	slight	30

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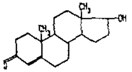
Androgens[1,2] (for references see page 753)

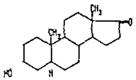
Chemistry

The androgens comprise a group of steroids the administration of which compensates for the effects of castration in the adult male animal and promotes the development of the male accessory reproductive glands and secondary sexual characteristics in the sexually immature animal

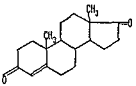
Testosterone



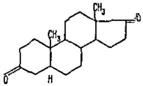
Androsterone
(androstan 3α-ol-17-one)



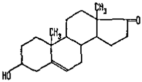
Androstenedione



Androstanedione



Dehydroepiandrosterone



Steroids with androgenic activity have also been synthesized example 17-methyltestosterone and fluoxymesterone[3]. Synt long-chain esters of testosterone (testosterone cypionate, t sterone enanthate, testosterone phenylacetate) show prolonge drogenic activity Other testosterone derivatives with an ana but less actively virilizing effect have been synthesized, for exa methandrostenolone, 19-nortestosterone, norethandrolone[4].

Unit

0 1 mg androsterone.

Methods of assay[5]

Androgenic activity can be measured biologically on birds (c

Biosynthesis, secretion, metabolism[9]

sponding amounts for the adrenal cortex being 2–3 mg 9–10 mg respectively[10] (see also page 743) Androstenedione

Leydig cells appears to be stimulated only by the gonadotr (LH HCG)[10,11] whereas adrenocortical synthe

Production rates of androgens (mg/24 h)

	Mean	Range	*s*	Reference
Testosterone				
Men	7	–	–	24
Women	0.34	–	–	24
Men	–	3.58–7.56	–	25
Women	–	0.42–0.94	–	25
Men	6.8	–	–	26
Women	0.23	0.13–0.33	0.073	27
Androstenedione				
Men	1.4	–	–	24
Women	3.4	–	–	24
Women	3.3	1.7–6.3	1.86	27
Epitestosterone				
Men	0.22	–	–	26

drogens in plasma

	Mean	Range	*s*	Reference
Testosterone (µg/l)				
Men	8.0	5–11	2.5	33
Women	0.69	–	–	33
Men	6.4	3.2–13.0	2.0	34
Women	0.36	0.13–0.80	0.09	34
Women	0.37	0.20–0.70	0.09	35
Pregnancy				
20–31 weeks	3.8	3.0–4.6	–	14
39–42 weeks	9.0	5.9–11.7	–	14
Androstenedione (µg/l)				
Adolescents	0.50	–	–	36
Men	0.60	–	0.12	37
Women	1.40	–	0.32	37
Women	1.67	0.9–2.1	0.40	35
Dehydroepiandrosterone sulphate (mg/l)				
Men	1.5	–	–	30
Women	1.0	–	–	30
Androsterone sulphate (mg/l)	0.4	–	–	30

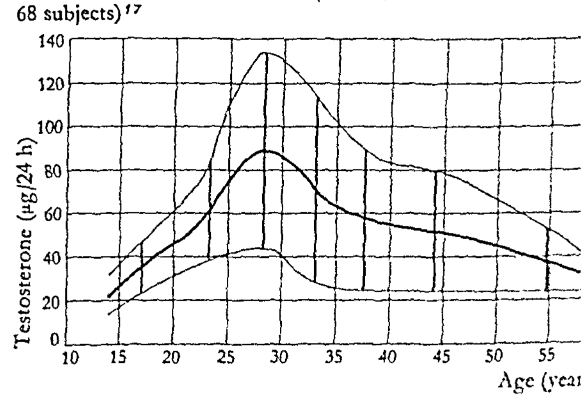
ı on testicular function in men[10] and on virilizing processes and ›pathic hirsutism in women[2].

Testosterone injected into the blood stream is rapidly broken vn, the half-life being about 4 min[16]. The most important akdown products of testosterone and androstenedione are ansterone and aetiocholanolone (see page 746), the excretion of ich is discussed in connection with the 17-ketosteroids in the secı on 'Corticosteroids', page 749. In urine, testosterone is present nly as the glucuronide, dehydroepiandrosterone mainly as the ›hate. Published data on the urinary excretion of testosterone conflicting, but recent values from which the variation with can be seen are shown in the table and figure on this page. Like plasma level, the urinary excretion of testosterone in women tuates during the course of the menstrual cycle[18,19], with a imum during and immediately following menstruation and a imum during the luteal phase of the cycle. The urinary testoone excretion may fall after the menopause[19].

Urinary testosterone excretion (µg/24 h)

	Mean	Range
Testosterone, total		
Children, < 10 years	0.4	0.1–0.8
Men	37	20–65
Women	7.7	3–14
Men, 16–20 years	78	60–103
Men, 21–63 years	51.7	40–65
Women, 20–55 years	6.5	2.1–10.7
Testosterone glucuronide		
Men	72	33–120
Women	12	7–18
Testosterone sulphate		
Men	–	~5–10
Testosterone, free		
Men	1.1	–
Women	0.7	–
Epitestosterone glucuronide		
Men	182	–
Women	36	–

Testosterone excretion in normal men (mean ± 2 × standard deviatior 68 subjects)[17]



Biological activity

Testosterone has an anabolic effect on protein metabolism and this hormone and its synthetic derivatives have been shown promote nitrogen retention and accelerate the recovery of perso suffering from nutritional protein deficiency. Testosterone h more marked effects on boys before puberty and on women tha on men. The site of action of the hormone in protein synthesis probably the transfer of the s-RNA/amino acid complex to th ribosomes.

Comparative activities of androgens[1]

	Capon comb test	Seminal vesicle test (rats)	Virilizing effect (women)
Testosterone	100	100	100
Androsterone	10	10	–
Androstenedione	12	20	<5
Androstanedione	12	14	–
Dehydroepiandrosterone	16	3	<5
Methyltestosterone	60	–	–

Synthetic progestational steroids are mostly derived from 17α-acetoxyprogesterone[2]. In addition to their progestational effect, derivatives of 19-nortestosterone have a marked androgenic action[2].

Methods of assay

Biological[3]. For clinical purposes biological tests are either not [illegible]

semicarbazone at 280 nm[5]. Fluorimetric, colorimetric and more recently gas-chromatographic and double isotope dilution techniques are also available. Pregnanediol is best determined colorimetrically, for instance by the method of KLOPPER et al.[6], or by gas chromatography.

Biosynthesis, secretion, metabolism[7,8]

Progesterone is an intermediary metabolite in the biosynthesis of all other steroid hormones, and is secreted by the adrenal cortex, ovaries, testes and placenta. The corpus luteum of the ovaries and the placenta are the quantitatively most important sources. The amount contained in these organs (corpus luteum ca. 20 µg/g[9], placenta 2–4 µg/g[10]) is small in comparison with the amount se- [illegible]

terone production remains roughly proportional to the weight of the placenta; at term it is about 250 mg per day[12].

*Production rates of progesterone and pregnenolone** (mg/24 h)

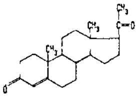
	Mean	Range	Reference
Progesterone			
Men	–	1.1–6.5	28
Men, 23–34 years	5.1	3.2–7.4	29
Men, 74–79 years	1.5	0.8–1.9	29
Women, ovariectomized	–	0.9–2.5	28
Women, proliferation phase	–	2.5–5.4	30
Women, luteal phase	–	22–43	30
Pregnenolone			
Men, 23–34 years	15	9–22	29
Men, 74–79 years	3.5	2.6–5.1	29

* Urinary production rates (obtained from urinary excretion of pregnanediol)

Plasma levels of progesterone and some of its metabolites are [illegible]

[illegible] is bound to plasma proteins, principally to albumin[14].

Metabolism. Injected progesterone disappears [illegible]



Plasma levels of progesterone and its metabolites (µg/l)

	Mean	Range	s	Reference
Progesterone				
Women, proliferative phase	–	0–5.3	–	31
Women, luteal phase	–	6–21	–	31
Women, proliferative phase	1.13	–	0.49	32
Women, luteal phase	10.4	–	3.2	32
Women, ovariectomized	0.39	–	0.10	32
Men	0.28	–	0.13	32
Men	0.28	<0.15–0.48	–	33
Umbilical vein	372	–	60	34
Umbilical artery	140	–	18	34
17α-Hydroxyprogesterone				
Women, proliferative phase	0.42	–	0.20	27
Women, luteal phase	1.74	–	0.46	27
Men	0.95	–	0.31	27
Umbilical vein	6	–	–	34
Umbilical artery	33	–	–	34
20α-Hydroxypregnenone				
Umbilical vein	10	–	–	34
Umbilical artery	27	–	–	34
20β-Hydroxypregnenone				
Umbilical vein	3	–	–	34
Umbilical artery	14	–	–	34
Pregnanediol				
Women	–	65–129	–	35

Urinary excretion of progesterone metabolites (mg/24 h)

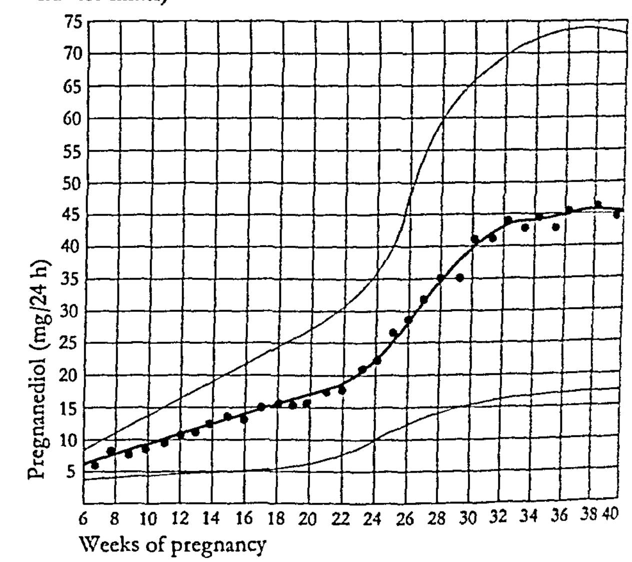
	Mean	Range	s	Reference
Pregnanediol				
Boys, 3–15 years	0.76	–	0.32	36
Girls, 3–15 years	0.72	–	0.60	36
Men	0.92	0.38–1.42	–	6
Women, proliferative phase	1.12	0.78–1.50	–	6
Women, luteal phase	3.3	2.1–4.2	–	6
Women, postmenopausal	0.63	0.28–0.86	–	6
Women, proliferative phase	0.48	0.10–1.26	0.31	37
Women, luteal phase	2.68	1.17–9.50	1.68	37
Men, 23–34 years	0.6	–	0.17	29
Men, 74–79 years	0.15	–	0.07	29
Pregnanolone				
Men	–	0.14–0.60	–	38
Women	–	0.06–0.46	–	38

70% of injected progesterone can be recovered from urine and faeces, and less than 40% can be accounted for as known metabolites[7].

During the proliferation phase of the menstrual cycle pregnanediol excretion is usually less than 1 mg/24 h; this pregnanediol probably originates mainly from the steroids formed in the adrenal cortex. After ovulation, pregnanediol excretion increases and in the luteal phase usually reaches 2–6 mg/24 h. In this phase the greater part of the pregnanediol arises from progesterone secreted by the corpus luteum. A few days before menstruation pregnanediol excretion begins to fall, reaching a minimum 2 or 3 days after the start of the period.

The progesterone formed in the placenta passes into the foetus, where it is broken down into less active compounds like 17α-hydroxyprogesterone and the 20α- and 20β-hydroxypregnenones. There is a dynamic exchange of progesterone and its metabolites between foetus and placenta, mother and placenta, and foetus and mother[17]. During pregnancy, the excretion of pregnanediol increases (see the diagram below), as does that of pregnanolone[19]; after parturition it falls again, reaching the proliferation phase value in about a week[20]. Pregnanediol has been isolated from the meconium, where it is present to the extent of 85–95% as sulphate[21].

Urinary pregnanediol excretion during pregnancy[18] (mean and 95% confidence limits)



Regulation of progesterone secretion. Little is known of the manner in which progesterone synthesis and secretion is regulated[2,7,22,23]. The formation of the hormone in the ripening follicle is probably stimulated only by LH; whether its secretion during the luteal phase is stimulated by prolactin as well as LH is not known for certain. The manner in which progesterone formation in the placenta is regulated has not been explained, but HCG may play a role in this. Under certain conditions, HCG has been observed to increase progesterone secretion in the corpus luteum.

Biological activity

The main action of progesterone is the maintenance of pregnancy[24], the mechanism of which is poorly understood[25], though it is known that progesterone blocks the spread of the uterine contractile response to oxytocin[24]. The hormone also has other effects on the uterus, notably on its composition and metabolic activity; thus it causes an increase not only of uterine weight but of the collagen, nucleic acid, glycogen and lipid contents of the organ. In many of its uterine effects progesterone acts only in conjunction with oestrogens[7].

The biological activity of progesterone is not confined to the reproductive cycle. The hormone has an inhibitory effect in vitro on enzymes of the respiratory chain and stimulates the metabolism of galactose[7]. It is antagonistic to the sodium-retaining effects of aldosterone and deoxycorticosterone but does not affect potassium excretion; progesterone administration is followed by a compensatory increase in aldosterone secretion. Progesterone has a catabolic effect and causes increased urinary nitrogen excretion; there is some evidence that this is due to inhibition of amino-acid utilization by the liver. In rats and mice, the hormone causes an increase in body weight due to deposition of fat. These general metabolic effects of progesterone probably have little physiological significance except when large amounts of the hormone are secreted.

ences

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Oestrogens (for references see page 757)

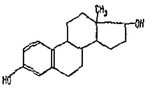
Chemistry

All naturally occurring oestrogens are unsaturated phenolic

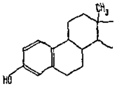
... urinary fraction

Oestrogenic activity is also seen in plant phenols such as genis-

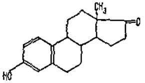
Oestradiol (17β-oestradiol)



Oestriol



Oestrone



Methods of assay

Biological[2] For example, induction of the characteristic

present

Chemical[3] Oestrogens can be determined colorimetrically reaction) or fluorimetrically

Biosynthesis, secretion, metabolism[4]

The biosynthesis of the oestrogens

(continued on)

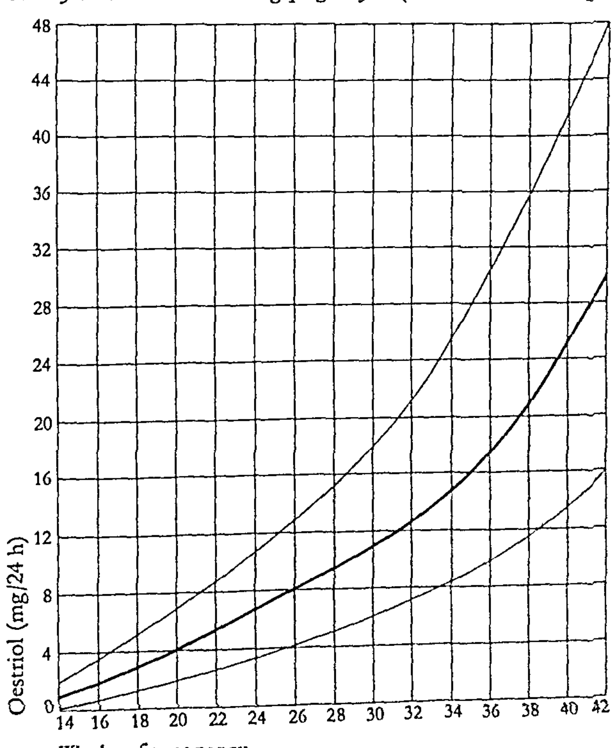
Production rates of oestradiol (µg/24 h)

	Mean	Range	♂
Women	–	200–500	–
Women	–	93–165	–
Women, mid-cycle	–	up to 300	–
Women, start of cycle	–	35–100	–
Men, 21–37 years	70	–	29

Oestrogens in plasma (µg/l)

	Mean	Range	*s*	Reference
Women				
Proliferative phase				
Oestriol	0.25	–	0.12	32
Oestrone	0.20	–	0.11	32
Oestradiol	0.13	–	0.08	32
Ovulation				
Oestriol	0.37	–	0.23	32
Oestrone	0.70	–	0.25	32
Oestradiol	0.28	–	0.17	32
Men				
Oestrone	0.42	–	0.09	33
Oestradiol	0.15	–	0.12	33
Oestriol	–	trace	–	34
Pregnancy				
36th–38th week				
Oestrone + oestradiol	92	–	32	35
Oestriol	81	–	35	35
39th–42nd week				
Oestrone + oestradiol	108	–	37	35
Oestriol	93	–	39	35
At term				
Oestriol	–	43–175	–	36
Oestrone	–	27–103	–	36
Oestradiol	–	13–29	–	36
Cord blood				
Oestriol	583	–	–	37
Oestrone	13	–	–	37
Oestradiol	6	–	–	37

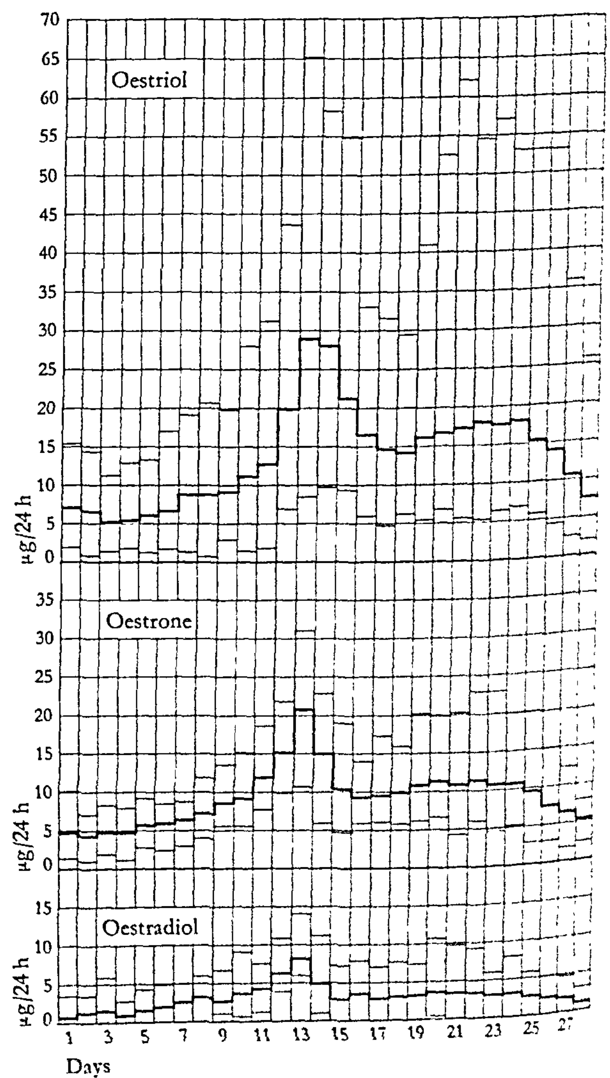
Urinary oestriol excretion during pregnancy[19] (mean and 95% range)



Urinary excretion of oestrogens (µg/24 h)

	Mean	Range	Reference
Children, 9–12 years			
Total oestrogens	–	<1.0	38
Women, postmenopausal			
Total oestrogens	5.5	3.2–9.0	20
Oestriol	3.9	2.2–7.5	20
Oestrone	1.3	0.3–2.4	20
Oestradiol	0.3	0–1.4	20
Men, 20–50 years			
Total oestrogens	10.3	6.0–17.8	39
Oestriol	3.5	0.8–11.0	39
Oestrone	5.4	3.0–8.2	39
Oestradiol	1.5	0–6.3	39
Pregnancy, 1 week ante partum			
Total oestrogens	30800	23200–37200	40
Oestriol	29000	22000–35000	40
Oestrone	1400	930–1600	40
Oestradiol	520	380–630	40

Urinary oestrogen excretion during the menstrual cycle[20] (mean and highest and lowest values in 16 women aged 18 to 41 years)



s Foetus, placenta and mother appear to be separate compart-
s in this respect, and not all oestrogens and oestrogen metabo-

ormal plasma oestrogen levels are given in the table opposite
e course of the menstrual cycle the highest values occur shortly

oid hormones, the oestrogens are the most strongly bound to
sma proteins[14]

inary oestrogen metabolites are 16-epioestriol, 16α-hydroxy-
strone, 16-keto-oestradiol, 16β-hydroxyoestrone, 2 methoxyoes-
one and 2 methoxyoestriol[16], as well as 15α-hydroxyoestrone,
β hydroxyoestrone and 15β-hydroxyoestradiol-17β[17]. The uri-
ry oestrogens are conjugated almost exclusively with glucuronic

Regulation of oestrogen secretion[27] Both FSH and LH appear to be necessary for oestrogen formation. The synthesis is also stimulated in men and women by HCG[7]

Biological activity

The oestrogens have a similar but weaker anabolic action on protein metabolism and cause retention of sodium and water

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Functions of the sex hormones

	Androgens	Oestrogens	Progesterone
Male organism			
Development of primary sex organs:			
General, especially testes, prostate, penis	+++	Antagonist	
Muscles and connective tissue of accessory glands	?	+	
Development of secondary sex characteristics	++++	Antagonist	
Emotional behaviour: libido, masculine activity	++++	Antagonist	
Female organism			
Development of primary sex organs	Partial antagonist	+++	0
Development of secondary sex characteristics	Antagonist	++++	?
Emotional behaviour:			
Frigidity	Antagonist	++++	+
Libido	+++	+	Partial antagonist
Menstrual cycle			
Maturation of ovum	?	+++	+
Proliferation phase	?	++++	+
Secretion phase	?	+	++++
Migration of ovum, nidation	?	++	+++
Pregnancy			
Inhibition of maturation of further follicles; quiescence of the uterus; relaxation of the uterine muscles (1); lowering of the Na:K ratio in blood; lowering of the sympathetic tonus (2)	?	Antagonist to (1); synergist to (2)	++++
Indispensable for maintenance of pregnancy	?	++	++
Relaxation of the pelvic girdle; increase of tonus of uterine muscles towards end of pregnancy (3)	?	+++	Antagonist to (3)
Growth of mammary tissue	?	++*	++*
Inhibition of lactation until parturition	?	++	+
Post partum			
Maintenance of lactation	?	++*	++*
Inhibition of lactation at high therapeutic dosage	++	+++++	0
Involution of the uterus and preparation for fresh menstrual cycle	?	+++	0

* See also under 'Prolactin', page 719.

International Biological Standards and Reference Preparations[1]

Substance	International Unit (IU) mg	Form in which dispensed	Year of establish
Antigens I — Held by International Laboratory for Biological Standards, Statens Seruminstitut, Copenhagen			
Old tuberculin	(0.011 111 µl)	Ampoules containing 2 ml (90 000 IU per ml)	1965 (3rd Star
Mammalian tuberculin (purified protein derivative)	0.000 28	Ampoules containing 10 mg plus 4 mg of salts (500 000 IU per ampoule)	1951 (1st Star
Avian tuberculin (purified protein derivative)	0.000 072 6	Ampoules containing 10 mg plus 26.3 mg of salts (500 000 IU per ampoule)	1954 (1st Star
Tetanus toxoid (alcohol-purified)	0.03	Ampoules containing 25 mg plus glycine (833 IU per ampoule)	1951 (1st Star
Tetanus toxoid (adsorbed)	0.666 7	Ampoules containing 80 mg adsorbed to aluminium hydroxide, plus an equal part of guinea-pig serum, dried (120 IU per ampoule)	1965 (1st Star
Diphtheria toxoid (alcohol-purified)	0.50	Ampoules containing 50 mg plus glycine (100 IU per ampoule)	1951 (1st Star
Diphtheria toxoid (adsorbed)	0.75	Ampoules containing 80 mg adsorbed to aluminium hydroxide plus an equal part of guinea pig serum, dried (107 IU per ampoule)	1955 (1st Star
Schick test toxin (diphtheria) (purified)	0.004 2	Ampoules containing 0.005 mg plus 1 mg of bovine albumin and 2.74 mg of phosphate buffer salts (900 IU per ampoule)	1954 (1st Star
Pertussis vaccine (dried)	1.5	Ampoules containing 52 mg (34.7 IU per ampoule)	1957 (1st Star
Cholera vaccine (Inaba) (dried)	–	Ampoules containing 20 mg (1.6×10^{10} organisms per ampoule)	1953 (1st Ref Prepara
Cholera vaccine (Ogawa) (dried)	–	Ampoules containing 20 mg (1.6×10^{10} organisms per ampoule)	1953 (1st Ref Prepara
Cardiolipin (purified)	–	Ampoules containing 4, 8 or 16 ml of a solution in ethanol (6.0 mg cardiolipin per ml as calculated from the phosphorus content)	1967 (4th Re Prepara
Lecithin (beef heart, purified)	–	Bottles containing 30 ml of a solution in ethanol (30.3 mg lecithin per ml)	1953 (2nd Re Prepara
Lecithin (egg, purified)	–	Ampoules containing 4, 8 or 16 ml of a solution in ethanol (26.7 mg of lecithin per ml as calculated from the phosphorus content)	1959 (3rd Re Prepara
Rabies vaccine	–	Ampoules containing 121 mg of a UV-inactivated, freeze-dried suspension of rabbit brain infected with fixed rabies virus	1965 (2nd Re Prepara
Smallpox vaccine (freeze-dried)	–	Ampoules containing 14 mg	1962 (1st Re Prepara
Typhoid vaccine (acetone-inactivated, dried)	–	Ampoules containing 11 mg	1962 (1st Re Prepara
Typhoid vaccine (heat-phenol-inactivated, freeze-dried)	–	Ampoules containing 34 mg	1962 (1st Re Prepara
Poliomyelitis vaccine ([illegible])	–	Ampoules containing 10 ml	1962 (1st Re Prepara
BCG vaccine (dried)	–	Ampoules containing dried vaccine derived from 2.5 mg (semi-dry weight) of bacillary mass of BCG and 5 mg of sodium glutamate (total weight of dried material 5.72 mg per ampoule)	1965 (1st Re Prepara
Influenza virus haemagglutinin type A (purified, freeze-dried)	0.093 651	[illegible]	1967 (1st Re Prepara
Antigens II — Held by International Laboratory for Biological Standards, Central Veterinary Laboratory, Weybridge, England			
Swine erysipelas vaccine (adsorbed, dried)	0.57	Ampoules containing 470 mg, derived from formalin-treated *Erysipelothrix rhusiopathiae (E. insidiosa)* type B, adsorbed to aluminium hydroxide (1300 IU per ampoule)	1959 (1st St
Newcastle disease vaccine (inactivated, freeze-dried)	1.0	Ampoules containing 525 mg of vaccine derived from formaldehyde treated allantoic fluid of eggs infected with strains of Newcastle disease virus adsorbed to aluminium hydroxide (525 IU per ampoule)	1963 (1st St
Newcastle disease vaccine (live, freeze-dried)	–	Ampoules containing 199.5 mg of allantoic fluid derived from eggs infected with the virus (Hitchner B_1 strain)	1967 (1st Re Prepar
Canine distemper [illegible] (freeze-dried)	–	Ampoules containing 53.4 mg	1966 (1st Re Prepar

[1] From WHO Expert Committee on Biological Standardization, *Wld Hlth Org. techn. Rep. Ser.*, No. 413 (1969).

Substance	International Unit (IU) mg	Form in which dispensed	Year of establishment
Antibodies I Held by International Laboratory for Biological Standards, Statens Seruminstitut, Copenhagen			
Tetanus antitoxin (hyperimmune horse serum, dried)	0.309 4	Bottles containing 10 ml of a solution in saline, containing 66 vol% glycerol (5 IU per ml)	1928 (1st Standard)
Diphtheria antitoxin (hyperimmune horse serum, dried)	0.062 8	Bottles containing 10 ml of a solution in saline, containing 66 vol% glycerol (10 IU per ml)	1922 (1st Standard)
Antidysentery serum (SHIGA) (hyperimmune horse serum, dried)	0.05	Bottles containing 10 ml of a solution in saline, containing 66 vol% glycerol (200 IU per ml)	1928 (1st Standard)
Gas-gangrene antitoxin *(perfringens)* (*Clostridium welchii* type A antitoxin; hyperimmune horse serum, dried)	0.334 6	Bottles containing 90.35 mg (270 IU per ampoule)	1963 (5th Standard)
Gas-gangrene antitoxin *(vibrion septique)* (hyperimmune horse serum, dried)	0.118	Ampoules containing 59 mg of a 1:3 dilution in phosphate-buffered saline (500 IU per ampoule)	1957 (3rd Standard)
Gas-gangrene antitoxin *(oedematiens)* (hyperimmune horse serum, dried)	0.082 8	Ampoules containing 91 mg (1100 IU per ampoule)	1966 (3rd Standard)
Gas-gangrene antitoxin *(histolyticus)* (hyperimmune horse serum, dried)	0.2	Bottles containing 10 ml of a solution in saline, containing 66 vol% glycerol (20 IU per ml)	1951 (2nd Standard)
Gas-gangrene antitoxin *(Sordelli)* (hyperimmune horse serum, dried)	0.133 4	Bottles containing 10 ml of a solution in saline, containing 66 vol% glycerol (20 IU per ml)	1938 (1st Standard)
Staphylococcus α antitoxin (hyperimmune horse serum, dried)	0.237 6	Bottles containing 10 ml of a solution in phosphate-buffered saline, containing 0.01 g thiomersal per 100 ml (20 IU per ml)	1938 (2nd Standard)
Scarlet fever streptococcus antitoxin (hyperimmune horse serum, dried)	0.049	Ampoules containing 490 mg (10 000 IU per ampoule)	1952 (1st Standard)
Anti-streptolysin O (human, dried)	0.021 3	Bottles containing 46 mg (2160 IU per ampoule); distributed as a 10 ml solution containing 10 IU per ml	1959 (1st Standard)
Antipneumococcus serum (type 1) (hyperimmune horse serum, dried)	0.088 6	Bottles containing 10 ml of a solution in saline, containing 66 vol% glycerol (200 IU per ml)	1934 (1st Standard)
Antipneumococcus serum (type 2) (hyperimmune horse serum, dried)	0.089 4	Bottles containing 10 ml of a solution in saline, containing 66 vol% glycerol (200 IU per ml)	1934 (1st Standard)
Anti-Q-fever serum (bovine, dried)	0.101 7	Ampoules containing 101.7 mg (1000 IU per ampoule)	1953 (1st Standard)
Antirabies serum (hyperimmune horse serum, dried)	1.0	Ampoules containing 86.6 mg (86.6 IU per ampoule)	1955 (1st Standard)
Anti-A blood-typing serum (human, dried)	0.346 5	Ampoules containing 88.7 mg (256 IU per ampoule)	1950 (1st Standard)
Anti-B blood-typing serum (human, dried)	0.352 0	Ampoules containing 90.1 mg (256 IU per ampoule)	1950 (1st Standard)
Anti-Rh_0 (anti-D) incomplete blood-typing serum (pooled human serum, dried)	0.95	Ampoules containing 30.4 mg (32 IU per ampoule)	1966 (1st Standard)
Syphilitic human serum (dried)	3.617	Ampoules containing 177.4 mg (49 IU per ampoule)	1958 (1st Standard)
Anti-poliovirus serum (type 1) (hyperimmune monkey serum, dried)	10.78	Ampoules containing 107.8 mg (10 IU per ampoule)	1962 (1st Standard)
Anti-poliovirus serum (type 2) (hyperimmune monkey serum, dried)	10.46	Ampoules containing 104.6 mg (10 IU per ampoule)	1962 (1st Standard)
Anti-poliovirus serum (type 3) (hyperimmune monkey serum, dried)	10.48	Ampoules containing 104.8 mg (10 IU per ampoule)	1962 (1st Standard)
Clostridium botulinum, Type A antitoxin (hyperimmune horse serum, dried)	0.136 0	Ampoules containing 68.0 mg (500 IU per ampoule)	1963 (1st Standard)
Clostridium botulinum, Type B antitoxin (hyperimmune horse serum, dried)	0.174 0	Ampoules containing 87.0 mg (500 IU per ampoule)	1963 (1st Standard)
Clostridium botulinum, Type C antitoxin (hyperimmune horse serum, dried)	0.080 0	Ampoules containing 80.0 mg (1000 IU per ampoule)	1963 (1st Standard)
Clostridium botulinum, Type D antitoxin (hyperimmune horse serum, dried)	0.012 1	Ampoules containing 12.1 mg (1000 IU per ampoule)	1963 (1st Standard)
Clostridium botulinum, Type E antitoxin (hyperimmune horse serum, dried)	0.069 1	Ampoules containing 69.1 mg (1000 IU per ampoule)	1963 (1st Standard)
Clostridium botulinum, Type F antitoxin (hyperimmune rabbit serum, dried)	7.44	Ampoules containing 29.32 mg (4 IU per ampoule)	1965 (1st Standard)
Naja antivenin (horse serum, polyvalent [*Naja* and *Hemachatus* species], purified, dried)	2.69	Ampoules containing 807 mg (300 IU per ampoule)	1964 (1st Standard)
Anti-smallpox serum (pooled human serum, freeze-dried)	0.084 16	Ampoules containing 84.3 mg (1000 IU per ampoule)	1965 (1st Standard)
Anti-toxoplasma serum (pooled human serum, freeze-dried)	0.090 967	Ampoules containing 181.934 mg (2000 IU per ampoule)	1967 (1st Standard)

Substance	International Unit (IU) mg	Form in which dispensed	Year of establishment
Diphtheria antitoxin for flocculation test (hyperimmune horse serum)	-	Bottles containing 10 ml of a dilution in phosphate-buffered saline, containing 0 01 g thiomersal per 100 ml (500 IU per ml)	1956 (4th Reference Preparation)
Antityphoid serum (hyperimmune horse serum, dried)	-	Ampoules containing dried material from 5 ml serum	1952 (1st Reference Preparation)
Anti-yellow-fever serum (monkey serum, dried)	0 5	Ampoules containing 71 5 mg (143 IU per ampoule)	1962 (1st Reference Preparation)
Anti-measles serum (human serum, dried)	9.378	Ampoules containing 93 8 mg (10 IU per ampoule)	1964 (1st Reference Preparation)
Anti-staphylococcal P-V leucocidin serum (horse serum, freeze-dried)	0 356 5	Ampoules containing 53 5 mg (150 IU per ampoule)	1965 (1st Reference Preparation)
Rheumatoid arthritis serum (pooled human serum, freeze-dried)	0 171	Ampoules containing 17 1 mg (100 IU per ampoule)	1965 (1st Reference Preparation)
Anti-rubella serum (pooled human serum, freeze-dried)	-	Ampoules containing 56 28 mg	1966 (1st Reference Preparation) (discontinued 1967)

Antibodies II

Held by International Laboratory for Biological Standards, Central Veterinary Laboratory, Weybridge, England

Anti *Brucella abortus* serum	0 095 52	Ampoules containing 95 52 mg of freeze-dried bovine serum (1000 IU per ampoule)	1967 (2nd Standard)
Clostridium welchii (perfringens) type B antitoxin (hyperimmune horse serum, dried)	0 013 7	Ampoules containing 68 5 mg (5000 IU per ampoule)	1954 (1st Standard)
Clostridium welchii (perfringens) type D antitoxin (hyperimmune horse serum, dried)	0 065 7	Ampoules containing 65.7 mg (1000 IU per ampoule)	1954 (1st Standard)
Swine erysipelas serum (anti-N) (hyperimmune horse serum, dried)	0 14	Ampoules containing 87 9 mg (628 IU per ampoule)	1954 (1st Standard)
Anti-swine-fever serum (pig serum, freeze dried)	0 89	Ampoules containing 889 5 mg (1000 IU per ampoule)	1963 (1st Standard)
Anti-canine-distemper serum (hyperimmune horse serum, freeze-dried)	0 089 7	Ampoules containing 89 7 mg (1000 IU per ampoule)	1967 (1st Standard)
Anti-canine-hepatitis serum (hyperimmune horse serum, freeze-dried)	0 079 6	Ampoules containing 79 6 mg (1000 IU per ampoule)	1967 (1st Standard)
Anti-Newcastle disease serum (chicken serum, freeze-dried)	0 173 4	Ampoules containing 55 5 mg (320 IU per ampoule)	1966 (1st Reference Preparation)

Antibiotics I

Held by International Laboratory for Biological Standards, National Institute for Medical Research, London

Streptomycin (sulphate)	0 001 282	Ampoules containing 175 mg (780 IU per mg)	1958 (2nd Standard)
Dihydrostreptomycin (sulphate)	0 001 219	Ampoules containing 200 mg (820 IU per mg)	1966 (2nd Standard)
Bacitracin (zinc bacitracin)	0 013 51	Ampoules containing 100 mg (74 IU per mg)	1964 (2nd Standard)
Tetracycline (hydrochloride)	0 001 01	Ampoules containing 200 mg (990 IU per mg)	1957 (1st Standard)
Chlortetracycline (hydrochloride)	0 001	Ampoules containing 60 mg (1000 IU per mg)	1953 (1st Standard)
Oxytetracycline (dihydrate)	0 001 136 4	Ampoules containing 100 mg (880 IU per mg)	1966 (2nd Standard)
Erythromycin (dihydrate)	0 001 053	Ampoules containing 200 mg (950 IU per mg)	1957 (1st Standard)
Polymyxin B (sulphate, purified)	0 000 127	Ampoules containing 19 mg (7874 IU per mg)	1955 (1st Standard)
Nystatin	0 000 333	Ampoules containing 75 mg (3000 IU per mg)	1963 (1st Standard)
Amphotericin B	0 001 064	Ampoules containing 100 mg (940 IU per mg)	1963 (1st Standard)
Vancomycin (sulphate)	0 000 993	Ampoules containing 50 mg (1007 IU per mg)	1963 (1st Standard)
Oleandomycin (chloroform adduct)	0 001 176	Ampoules containing 75 mg (850 IU per mg)	1964 (1st Standard)
Novobiocin (acid)	0 001 031	Ampoules containing 100 mg (970 IU per mg)	1965 (1st Standard)
Colistin (sulphate)	0 000 048 78	Ampoules containing 75 mg (20 500 IU per mg)	1968 (1st Standard)
Rolitetracycline	0 001 004	Ampoules containing 100 mg (996 IU per mg)	1968 (1st Standard)
Kanamycin (sulphate)	0 001 232	Ampoules containing 50 mg (812 IU per mg)	1959 (1st Reference Preparation)
Kanamycin B	-	Ampoules containing 5 mg	1964 (1st Reference Preparation)
Viomycin (sulphate)	0 001 37	Ampoules containing 35 mg (730 IU per mg)	1959 (1st Reference Preparation)

Substance	International Unit (IU) mg	Form in which dispensed	Year of establishment
		Antibiotics I (continued)	
Penicillin K (89.9% pure sodium *n*-heptylpenicillin, with 9.6% penicillin dihydro F and 0.5% penicillin F)	–	Ampoules containing 20 mg	1951 (1st Reference Preparation)
Neomycin (sulphate)	0.001 47	Ampoules containing 100 mg (680 IU per mg)	1958 (1st Reference Preparation)
Ristocetin	–	Ampoules containing 45 mg	1960 (1st Reference Preparation)
Ristocetin B	–	Ampoules containing 5 mg	1964 (1st Reference Preparation)
Gramicidin S	0.001 002	Ampoules containing 50 mg (998 IU per mg)	1962 (1st Reference Preparation)
Gramicidin	0.001	Ampoules containing 55 mg (1000 IU per mg)	1966 (1st Reference Preparation)
Spiramycin (base)	0.000 312 5	Ampoules containing 50 mg (3200 IU per mg)	1962 (1st Reference Preparation)
Demethylchlortetracycline	0.001	Ampoules containing 80 mg (1000 IU per mg)	1962 (1st Reference Preparation)
Triacetyloleandomycin	0.001 2	Ampoules containing 100 mg (833 IU per mg)	1962 (1st Reference Preparation)
Procaine benzylpenicillin in oil with aluminium monostearate	–	Vials containing 10 ml	1966 (2nd Reference Preparation)
Paromomycin (sulphate)	0.001 333	Ampoules containing 75 mg (750 IU per mg)	1965 (1st Reference Preparation)
Colistin methane sulphonate	0.000 078 74	Ampoules containing 75 mg (12 700 IU per mg)	1966 (1st Reference Preparation)
Cephalothin (cefalotin) (sodium cephalothin)	0.001 066 1	Ampoules containing 50 mg (938 IU per mg)	1965 (1st Reference Preparation)
Lincomycin (hydrochloride)	0.001 135 1	Ampoules containing 50 mg (881 IU per mg)	1965 (1st Reference Preparation)
Capreomycin (sulphate)	0.001 087	Ampoules containing 80 mg (920 IU per mg)	1967 (1st Reference Preparation)
Rifamycin SV (sodium rifamycin SV)	0.001 127	Ampoules containing 100 mg (887 IU per mg)	1967 (1st Reference Preparation)
Gentamycin (sulphate)	0.001 56	Ampoules containing 50 mg (641 IU per mg)	1968 (1st Reference Preparation)
Lymecycline	0.001 107	Ampoules containing 50 mg (903 IU per mg)	1968 (1st Reference Preparation)
		Antibiotics II Held by International Laboratory for Biological Standards, Central Veterinary Laboratory, Weybridge, England	
Tylosin (base)	0.001	Ampoules containing 40 mg (1000 IU per mg)	1966 (1st Standard)
Hygromycin B	0.000 892 8	Ampoules containing 40 mg (1120 IU per mg)	1966 (1st Standard)
		Hormones, Vitamins, Enzymes Held by International Laboratory for Biological Standards, National Institute for Medical Research, London	
Oxytocin and vasopressin (antidiuretic hormone) for bioassay (posterior ox pituitary, acetone-dried, powdered)	0.5	Ampoules containing 30 mg (2 oxytocic, 2 vasopressor and 2 antidiuretic IU per mg)	1957 (3rd Standard)
Prolactin for bioassay (active principle from anterior sheep pituitary, dried)	0.045 45	Ampoules containing 10 mg (22 IU per mg)	1962 (2nd Standard)
Corticotropin (ACTH) for bioassay (from anterior pig pituitary, purified)	1.0	Ampoules containing 50 mg with lactose, freeze-dried (1 IU per mg)	1962 (3rd Standard)
Thyrotropin for bioassay (from anterior ox pituitary, purified)	13.5	Ampoules containing ten 20-mg tablets of a blend of 1 part thyrotropin and 19 parts lactose (ca. 1.48 IU per tablet)	1954 (1st Standard)
Growth hormone for bioassay (active principle from anterior ox pituitary, dried)	1.0	Ampoules containing 30 mg (1 IU per mg)	1955 (1st Standard)
Growth hormone for immunoassay (from human anterior pituitary, purified)	24.29	Ampoules containing 8.5 mg with sucrose (0.350 IU per ampoule)	1968 (1st Reference Preparation)

Substance	International Unit (IU) mg	Form in which dispensed	Year of establishment
Human menopausal gonadotropins for bioassay (active principle from urine of post-menopausal women, freeze-dried)	0 229 5	Ampoules containing 9 *mg diluted with lactose (40 follicle*-stimulating hormone IU and 40 interstitial cell-stimulating hormone IU per ampoule)	*1964 (2nd Reference Preparation)*
Serum gonadotropin for bioassay (from serum of pregnant mares)	0 003 569	Ampoules containing 5 71 mg with lactose, freeze-dried (1600 IU per ampoule)	1966 (2nd Standard)
Chorionic gonadotropin for bioassay (active principle from human urine of pregnancy)	0 001 279	Ampoules containing 7 mg diluted with lactose, dried (5300 IU per ampoule)	1963 (2nd Standard)
Insulin for bioassay (52% bovine and 48% porcine pancreas, purified)	0 041 67	Ampoules containing 110–125 mg (24 IU per mg)	1958 (4th Standard)
Erythropoietin for bioassay *(from human urine)*	1 48	Ampoules containing 14 80 mg with lactose (0 675 7 IU per mg)	1965 (1st Reference Preparation)
Heparin (sodium salt of purified active principle from bovine lung tissue)	0 007 7	Ampoules containing 20 mg (130 IU per mg)	1958 (2nd Standard)
Vitamin D_3	0 000 025	Bottles containing 6 g of a solution in vegetable oil (1000 IU per g)	1949 (2nd Standard)
Vitamin B_{12} (cyanocobalamin)	–	Ampoules containing ten 20-mg tablets	1959 (1st Reference Preparation)
Hyaluronidase (from bovine testes, dried)	0 1	Ampoules containing ten 20-mg tablets diluted with lactose (ca 200 IU per tablet)	1955 (1st Standard)
Streptokinase-streptodornase (active material, dried)		Ampoules containing 1 mg with 5 5 mg of lactose (3100 streptokinase IU and 2400 streptodornase IU per ampoule)	1964 (1st Standard)
Streptokinase	0 002 090		
Streptodornase	0 002 700		
Urokinase (from human urine, purified)	0 001 410	Ampoules containing 6 77 mg with *lactose, freeze-dried* (4800 IU per ampoule)	*1968* (1st Reference Preparation)

Miscellaneous I

Held by International Laboratory for Biological Standards, *National Institute* for Medical Research, London

Substance	International Unit (IU) mg	Form in which dispensed	Year of establishment
Digitalis (dry powdered leaf of *Digitalis purpurea*)	76 0	Ampoules containing 2500 mg (0 013 16 IU per mg)	1949 (3rd Standard)
Neoarsphenamine	–	Ampoules containing 300 mg	1940 (3rd Reference *Preparation)*
Sulpharsphenamine	–	Ampoules containing 300 mg	1951 (3rd Reference Preparation)
Oxophenarsine (hydrochloride)	–	Sets of 3 ampoules *containing* (a) 120 mg oxophenarsine hydrochloride (b) 100 mg anhydrous sodium carbonate (c) 500 mg anhydrous sucrose	1951 (1st Reference Preparation)
Mel B (melaminyl-4 phenylarsenodithioglycerol)	–	Ampoules containing 100 mg	1954 (1st Reference Preparation)
MSb (sodium *p*-melaminylphenylstibonate polymer)	–	Ampoules containing 500 mg	1954 (1st Reference Preparation)
Dimercaprol (BAL 2,3-dimercaptopropanol)	–	Ampoules containing 2 ml	1952 (1st Reference *Preparation)*
Protamine	–	Ampoules containing *60 mg*	1954 (1st Reference Preparation)
Pyrogen *(purified 'O' antigen of Shigella dysenteriae dried)*	–	Ampoules containing 2 mg	1958 (1st Reference Preparation)

Miscellaneous II

Held by International Laboratory for Biological Standards, Statens *Seruminstitut,* Copenhagen

Substance	International Unit (IU) mg	Form in which dispensed	Year of establishment
Opacity reference preparation (aqueous suspension of pyrex glass particles)	–	Ampoules containing 15 ml (10 IU *of opacity per ml*)	1963 *(3rd Reference Preparation)*

Miscellaneous III

Held by Rijks Instituut voor de Volksgezondheid, Utrecht

Substance	International Unit (IU) mg	Form in which dispensed	Year of establishment
Haemiglobincyanide reference preparation	–	Ampoules containing 10 ml of haemiglobincyanide solution	1967 *(1st Reference Preparation)*

Substance	Form in which dispensed	Year of establishment
International Biological Reference Reagents **Reference Reagents I** Held by International Laboratory for Biological Standards, Statens Seruminstitut, Copenhagen		
Anti-tick-borne encephalitis sera:		
Anti-tick-borne encephalitis serum (louping ill [Moredun] virus)	Ampoules containing 1 ml of freeze-dried sheep serum	1964 (1st Reference Reagent)
Anti-tick-borne encephalitis serum (Russian spring-summer encephalitis [Sophyn and Absettarov] virus)	Ampoules containing 2 ml of freeze-dried sheep serum	
Cholera agglutinating serum (Ogawa)	Ampoules containing 1 ml of monospecific serum	1967 (1st Reference Reagent)
Anti-trichinella human serum	Ampoules containing 1 ml of freeze-dried pooled human serum	1968 (1st Reference Reagent)
Enterovirus antisera:		
Coxsackie virus antisera types A9, B1, B2 and B3	Ampoules containing 0.5 ml of freeze-dried monkey serum	1965 (1st Reference Reagent)
Coxsackie virus antisera types B4 and B5 Echovirus antisera types 1, 2, 3, 4, 5, 6, 6^1, 6^{11}, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 and 25 Poliovirus antisera types 1, 2 and 3 Reovirus antiserum type 1	Ampoules containing 0.5 ml of freeze-dried monkey serum	1966 (1st Reference Reagent)
Adenovirus antisera:		
Types 1, 2, 3, 5, 6, 7a, 8, 9, 10, 11, 13, 15 and 17	Ampoules containing 0.5 ml of freeze-dried horse serum	1966 (1st Reference Reagent)
Types 12 and 18	Ampoules containing 0.5 ml of freeze-dried horse serum	1967 (1st Reference Reagent)
Parainfluenza virus antisera: Types 1, 2 and 3 Mycoplasma pneumoniae antiserum	Ampoules containing 0.5 ml of freeze-dried horse serum	1968 (1st Reference Reagent)
Reference Reagents II Held by WHO/FAO and WHO Leptospirosis Reference Laboratories		
Anti-*Leptospira* sera:		
Anti-*Leptospira interrogans* serotype *saxkoebing* serum Anti-*Leptospira interrogans* serotype *castellonis* serum Anti-*Leptospira interrogans* serotype *sejroe* serum Anti-*Leptospira interrogans* serotype *mini* serum Anti-*Leptospira interrogans* serotype *australis* serum Anti-*Leptospira interrogans* serotype *copenhageni* serum Anti-*Leptospira interrogans* serotype *tarassovi* serum Anti-*Leptospira interrogans* serotype *autumnalis* serum Anti-*Leptospira interrogans* serotype *rachmati* serum Anti-*Leptospira interrogans* serotype *pomona* serum Anti-*Leptospira interrogans* serotype *bataviae* serum Anti-*Leptospira interrogans* serotype *hebdomadis* serum Anti-*Leptospira interrogans* serotype *andamana* serum Anti-*Leptospira interrogans* serotype *javanica* serum Anti-*Leptospira interrogans* serotype *pyrogenes* serum	Ampoules containing 0.5 ml or 1.0 ml of hyperimmune rabbit serum, dried	1958 (1st Reference Reagent)
Anti-*Leptospira interrogans* serotype *naam* serum Anti-*Leptospira interrogans* serotype *mankarso* serum Anti-*Leptospira interrogans* serotype *sarmin* serum Anti-*Leptospira interrogans* serotype *poi* serum Anti-*Leptospira interrogans* serotype *schueffneri* serum Anti-*Leptospira interrogans* serotype *muenchen* serum Anti-*Leptospira interrogans* serotype *cynopteri* serum Anti-*Leptospira interrogans* serotype *bangkinang* serum Anti-*Leptospira interrogans* serotype *wolffi* serum Anti-*Leptospira interrogans* serotype *hardjo* serum Anti-*Leptospira interrogans* serotype *kremastos* serum Anti-*Leptospira interrogans* serotype *benjamin* serum Anti-*Leptospira interrogans* serotype *zanoni* serum Anti-*Leptospira interrogans* serotype *medanensis* serum Anti-*Leptospira interrogans* serotype *paidjan* serum	Ampoules containing 0.5 ml or 1.0 ml of hyperimmune rabbit serum, dried	1962 (1st Reference Reagent)
Anti-*Leptospira interrogans* serotype *semaranga* serum	Ampoules containing 1.0 ml of hyperimmune rabbit serum, dried	1962 (2nd Reference Reagent)
Anti-*Leptospira interrogans* serotype *canicola* serum Anti-*Leptospira interrogans* serotype *grippotyphosa* serum Anti-*Leptospira interrogans* serotype *icterohaemorrhagiae* serum	Ampoules containing 0.5 ml of hyperimmune rabbit serum, dried	1966 (2nd Reference Reagent)
Anti-*Leptospira interrogans* serotype *atlantae* serum Anti-*Leptospira interrogans* serotype *georgia* serum Anti-*Leptospira interrogans* serotype *bratislava* serum Anti-*Leptospira interrogans* serotype *erinacei-aurati* serum Anti-*Leptospira interrogans* serotype *coxi* serum Anti-*Leptospira interrogans* serotype *fugis* serum Anti-*Leptospira interrogans* serotype *worsfoldi* serum Anti-*Leptospira interrogans* serotype *malaya* serum	Ampoules containing 0.5 ml or 1.0 ml of hyperimmune rabbit serum, dried	1966 (1st Reference Reagent)

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